Photogrammetry in the Visualization Era

Petros PATIAS, **Greece**

Key words: Photogrammetry, visualization, cultural heritage

SUMMARY

The purpose of this paper is multiple: First, to present and describe the available techniques and tools. The aim is not to exhaustively present these techniques. The interested reader can consult the existing vast literature for this; it is rather to highlight the most important features, which may be useful to the photogrammetrists. Second, to present and analyze the most common and important shortcomings of the current visualization technology, that have an impact on visualization of the photogrammetric data. These problems are currently a bottleneck in the photogrammetric visualization "pipeline". Currently, many research efforts are aiming at smoothing out these sharp edges. The proposed (and sometimes implemented and available) solutions are of much importance and interest to the photogrammetric community. They are analyzed too. Third, a critical survey of the current (during the last three years) visualization efforts and achievements in the photogrammetric community show the current status of achievement and what maybe expected in the future.

Photogrammetry in the Visualization Era

Petros PATIAS, **Greece**

1. INTRODUCTION

Much of the developed world is envisaging nowadays a user-friendly Information Society, where the emphasis is on greater user-friendliness, more efficient services support, user-empowerment, and support for human interactions. In this envisaged societal and economic environment, in the next ten years, Photogrammetry has to find its own way of evolvement, contribution and doing business. Therefore it will be multiply beneficial for photogrammetrists to set up our long- and middle-range aims taking also into consideration what might be called a "collective vision".

Photogrammerty has always been a technique that provides accurate, detailed, 3D data in a cost-effective way. Compared to other techniques, Photogrammetry shows distinct advantages. Not underestimating the fact that in many instances, Photogrammetry needs to couple its data with data from other sensors and other techniques, it is valid to state that Photogrammetry's comparative advantage is that it:

- provides *large amounts of data*, which can be of many scales and resolutions, refer to whole areas or to single objects, and are based merely on photogrammetric measurements or on combinations with other types of measurements.

- provides *very accurate data*, which, under the current technology, is routinely on the order of $^1/_3$ to $^1/_{10}$ of the pixel size. More importantly, the whole procedure is regularly monitored and checked to ensure that accuracy. And not only the accuracy is known; statistical inferences about it are also been drawn.

- provides *3-Dimensional data*, whether it refers to a whole area, city, or small archaeological finding. Photogrammetry, by its nature, reconstructs the 3D surface of objects in a detailed and accurate way.

- provides *texture data*, besides the 3D vector data. This is natural since the technique is based upon images of the objects to be reconstructed. Texture data are very important since it gives a natural looking to reconstructed 3D objects, enhancing thus the users cognition. More importantly, this texture also carries the 3D objects geometry; it has therefore metric characteristics matched with those of the vector data.

- provides *high resolution and detailed data*, both in vector and in texture. Based on the current high rates of advancements in technology, photogrammetric sensors are capturing more and more detailed data, which in turn are processed by increasingly effective automatic procedures. Centimeter-level pixel sizes are routinely realized in medium-scale mappings, and it goes down to millimeter-level or less when we refer to close-range mappings.

- provides *geo-referenced data*, that is all the above data refer to common reference frames, whether they are global or local coordinate systems. By reference to common ground coordinate systems, the metric characteristics of the data gain one more important advantage: they all refer to real-world geometry.

- provides *metada*, that is information about the data, which is quite natural since Photogrammetry captures, processes and provides the data. Metadata is quite useful, since they can be used for tracing down original sources, acquisition times, qualities, metrics, even ownership of the data; for both original and processed ones.

- in addition to all the above, it provides *stereo-viewing capabilities* of the 3D data, since the technique is by definition based on stereoscopic images. Among the others, this is a unique characteristic of the photogrammetric data and is not shared by other techniques.

In order for Photogrammetry to capitalize on its comparative advantage, there are two options, not necessarily mutually exclusive:

- Either *popularize the output data*, that is making the data available to as many users and for as many applications possible,
- Or *popularize the technique*, that is making the technique readily available in a user-friendly environment to as many non-photogrammetrists, end-users possible.

Although it is a matter of policy which goal to pursue most and to what degree, both goals are demanding and require extensive research. Pursuing any of the above goals, speaking in contemporary terms, it fatefully involves the use of Internet as a resource and Visualization as a means. There is no better way today to popularize either the outcome data or the technique other than using widely accessible web-based applications in a user-friendly visualization manner. But this should be done baring always in mind what new, more qualitative and less costly Photogrammetry has to offer, in contrast to other data sources.

The first goal seems to be the most demanding. Over the years, it also attracted the most interest, in research terms, by the photogrammetric community. Nowadays, from the point of view of Visualization, it seems that we are in the same position we were about 15 years ago when GIS systems were introduced. It took Photogrammetry many years to get familiar with the new technology, set its requirements, participate to fora for developing standards, do research on adding value on its data, and capitalize on its comparative advantage. The issue of Visualization seems to be in a similar stage:

- Visualization tools are been developed not by photogrammetrists; mostly not having in mind their needs either. The result is they work well with small and simple datasets but unpredictably with the massive and complex photogrammetric data. Specialized visualization tools claiming handling of such large datasets are only designed for high-end systems, which contradicts to one of our main goals.

- Photogrammetrists are often called upon to use low-end tools to visualize high-end data; the alternative being to make up their own tools. The result is that almost all photogrammetric visualization examples and good practices, shown over the last five years (with only rare exceptions, which only emphasize the rule), are rather generic and are based on the available low-end capabilities of the tools. This has a very serious consequence: It violates the central idea of investing on the Photogrammetry's comparative advantage. The valuable information contained in the photogrammetric data is "summarized" in order to be able to be visualized. The accuracy of the data is eliminated altogether (most of the software use only single precision), the geo-referencing disappears (the most used tools use their own coordinates only), the high resolution of both vectors and texture is unusable (intelligent texture mapping and effective LoD creation is rear in the most popular viewers), the large amounts of data prohibits any degree of interaction (permitting it only to high-end systems), and metadata information cannot be carried along with the images (current data format do not allow it). So what happens finally is that photogrammetrists settle for what is only available. But the visualization of such highly generalized data is not attracting any more the end-users, nor can it motivate new applications. Moreover, it cannot justify any more the high cost of the photogrammetric data, simply because there are other techniques that can produce such low-end, "summarized" data much more efficiently in time and cost. So the advantage of photogrammetry is lost altogether.

- Visualization software is been developed in very high rates over the last five years, too high sometimes for photogrammetrists to get familiarized, digest and use. Judging from the current status of the available technology and the on-going photogrammetric research, it seems that photogrammetrists do not follow closely the advancement of the technology. They are coming short at least 3 years and the gap is deepening in increasing rate.

- Photogrammetry is currently below other disciplines in the visualization arena. Photogrammetrists are not participating in the international fora, which discuss and decide upon the standards and the requirements to be set for the next generation visualization tools. If this will continue, more likely the above mentioned problems will become bigger.

2. A CLASSIFICATION OF EXISTING TOOLS

Visualization tools come in different colors and flavors. Their capabilities vary extensively and the same happens with the requirements they impose on the user. Above all, new tools become available every day. So, a categorization and complete survey of the available tools seems to be rather a work for Sisyphus: by the time the stone is pushed at the peek of the hill, it rolls down again. Instead of doing a complete categorization and survey of the existing tools we will attempt to construct broad categories and present characteristic examples. Such broad categories can be:

- *Generic Tools*, which are either generic languages (like GML(URL1), VRML(URL2), or OpenGL(URL3)) or suites of modules (like DirectX(URL4)). Their aim is to support the development of actual visualization tools.

- *Primitive Tools*, (usually public domain software, like PolyTRIM(URL5)) which support visualization but in a test-version manner. Some of them are still developing, but their use is usually problematic. Game Engines can fit in this category too, although their capabilities cover quite a wide range. Normally this category of tools depend their development on the Generic Tools, mentioned above. Exceptions, however, are not rare (eg. most Game Engines) making the border of the two categories above very foggy.

- *Programmable Visualization Toolkits*, (like TGS OpenInventor C++(URL6) or RSI's IDL(URL7)) which are built on top of Generic and/or Primitive Tools and are thus one level higher. Their aim is to provide visualization toolkits to the ambitious developer, rather than to be used as visualization tools themselves. Their basic difference to the other categories is that they do not require basic programming from the part of the developer, since they already provide highly programmed modules.

- *High-end Visualization Tools*, (like the Erdas' VirtualGIS(URL8) or PCI's Geomatics FLY! (URL9)) which are usually "turn-key" approaches and do not require user programming, although they usually give some liberty in doing so. Normally they can coop with large datasets, high-resolution images, etc. and are on continuous development. Their aim is not to be on the high-tech-visualization-edge but rather to cover usual visualization needs. They combine visualization with other functions (eg. Photogrammetry (eg. VirualGIS), Remote Sensing (eg. FLY!), GIS (eg. ArcInfo)) to an attempt to give end-to-end solutions, but they leave other specialized packages to solve specific problems (eg. they do not perform "paging" of very large datasets, like TerraPage or OpenFlight). In short, they are rather easy to use by a non programmer, they cover the usual visualization needs and provide the usual visualization products, but one cannot rely on them for specialized tasks, apart from the fact that they usually refer to visualization of big areas (with the exception of 3DS max) and only marginally to close-range objects.

- *Low-end Visualization Tools*, (like ShapeCapture(URL10) or PhotoModeler(URL11)) like the above high-end tools, need no programming and provide for even less visualization products. They usually refer to close-range objects and more often combine the visualization with the reconstruction. Although ShapeCapture and Photomodeler could be considered as the two ends in the 3D reconstruction process, in terms of visualization they rather posses very similar capabilities.

3. LIMITATIONS OF EXISTING TOOLS - PROPOSED SOLUTIONS

In dealing with the problems of the existing visualization tools, we will, on purpose, exclude the problems associated with data acquisition and modelling phase. We are going to concentrate on the problems merely of the existing visualization tools, and more specifically on the restrictions they impose on the visualization of large datasets, derived either by pure or combined photogrammetric means.

Photogrammetric data, whether it refers to terrain or to close-range 3D objects, are typically massive in size. This results in a dataset that is often too large and prohibits any form of real-time interaction or even visualization. Several approaches can be used to reduce this problem (see eg. Boulanger et al, 2000), which, in short, can be coded as *Level-of-Detail* creation (LoD), and *Image-based Rendering* (IBR).

All these techniques are inter-connected to each other and also degenerate in smaller technical problems. Besides, they result to efficient *DataBase* structures and effective optimized software. Two additional problems, in terms of photogrammetric data, exist; namely *Geo-referencing* and *metadata inclusion.*

(a) Image-based Rendering. This problem used to be referred to as "Texture Mapping", originated from the mapping of synthetic, computer-generated texture on 3D object surfaces. We prefer the more recent term "Image-based Rendering (IBR)" since it actually emphasizes the use of real-world images instead of synthetic surfaces. We acknowledge, however, the fact that IBR goes beyond the previous point: the motivating idea behind IBR was the generation of new views, based on given images. The reader should also note that the term "Impostors" (usually when referring to visualization of a simplified far-field) is used instead. This is originated from the fact that IBR is used to replace part (or all) of the 3D object's geometry rendering. The problem in Image-based rendering is actually a multiple one and can be degenerated into the following:

- *If a particular patch of the 3D object surface is imaged in several images, what is the best way to select the "most appropriate" image to be used for texture extraction?*
- *Then, how this texture should be re-projected on the patch, so as to have the least distortion?*
- *How this projection should be done in order to avoid occlusions or hidden parts?*
- *What algorithms can be used in order to generate novel views, and not only the ones from pre-defined viewpoints?*
- *Can it be done in real-time?*

It is apparent that question 3 is connected also to polygon culling and LoD generation, whereas question 5 is obviously connected to LoD generation and DataBase structure.

Although there are many advantages in using IBR, there exist certain disadvantages, which such techniques are trying to overcome by using some sort of representation of the scene either from the photographs or from underlying assumptions about the geometry of the object, like:

- *Non-physically based image mapping* (the interested reader may refer to Chen and Williams, 1993; Kang, 1997 and 1998; McMillan et al, 1995; Szeliski, 1996; or Pollefeys et al, 1999 for such techniques);
- *Mosaicking* (see eg. Debevec, 1999);
- *Interpolation from dense samples* (using LUT's)
- *Projective Rectification* (either for planar (eg. Guerra et al, 1999) or analytical surfaces (eg. Karras et al, 1996 and 1997)
- *Projective IBR* (where the 3D object surface is obtained by reconstruction of many small facets, eg. Neyret and Cani, 1999; El-Hakim et al, 1998; Segal et al, 1992; Hanke et al, 1999; Spann et al, 2000; Sequeira et al, 1999; Ng et al, 1998; Visnovcova et al, 2001)

(b) LoD Generation. The problem of LoD generation refers actually to two different things, which are not always distinguished in the literature. LoD notion applies to both vector and texture data. In order to distinguish them, we will refer to the first as Polygon Simplification and to the second as Texture Simplification. There are many similarities between them, and many differences as well. The general problem of LoD generation is a central one, meaning that it is connected to almost all other problems. It originates mainly from the need for real-time visualization using low-end resources and Internet-based applications. We can descriptively define it as follows:

- *Given a set of polygons (facets) that describe a 3D surface, how these should be represented at a number of resolutions, so that, depending on the viewer's position, details that are not visible will not to be shown?*
- *In doing that, how we can project only the visible ones?*
- *Given a set of texels (texture on the facets), how these should be represented at a number of resolutions, so that, depending on the viewer's position, details that are not visible will not to be shown?*
- *What data formats and DataBase structures can support these representations?*
- *What is the best way to navigate through the different LoD?*
- *Can we perform the visualization in real-time?*

Polygon simplification simplifies the geometry of the object depending on its size or distance to the viewer with minimal loss of visual contents. One way to reduce the data (and to a degree to coop with the visibility problem) is the use of Delaunay Triangulation, a mature segmentation technique most of the related software use nowadays (eg. Aurrenhammer, 1992; Woodhouse et al, 1999; Boochs et al, 1998). Another way to compress the model (specifically when the surface can be described by geometric objects) is to represent it by geometric primitives or parametric surfaces (Constructive Solid Geometry) at different levels.

Most methods (refer to (Heckbert and Garland, 1997), (Luebke, 1997) for surveys of existing methods) can be divided to those based on: (a) Decimation or removing polygons and retriangulating the resulting hole (eg. Soucy and Laurendeau, 1996); and (b) Merging or collapsing several vertices together into one vertex (eg. Hoppe, 1996).

Like the above, there are several texture simplification techniques, which if used together they provide for a mechanism for simplification of the geometry and the imagery of the dataset. However, most of these are view-independent techniques that force the same degree of simplification across the entire object. These tend to be inappropriate for web-based applications because switching to the highest resolution would still involve loading every point of the original dataset. A tiled pyramid approach is a common solution. This involves taking a high-resolution dataset and progressively down-sampling it to produce a multi-resolution pyramid. An example of such an approach is ISR's TerraVision II VRML browser (Reddy et al, 1998, 1999a, b, c) (URL12).

Two usual problems should be noted here: The first one concerns the often-noticed "pop-up effect"; when LoD's are switched, sudden appearances of objects not mapped in the previous LoD are occurring. The second one concerns the merging of different level LoD tiles in the same screen; if a more detailed LOD tile is displayed next to a less detailed tile and their edges don't match, gaps appear along the edges. One solution is offered by the Terrex's "SmartMesh" (URL13), which eliminates this effect by allowing the perimeter of a tile to change between LOD's while still maintaining an unbroken surface. It uses quadtree database structure and works with unlimited number of LoD's.

Once the LoDs are formed, the navigation through the different levels generally follows one of the two approaches: (a) Anchor/LoD files (eg. Zlatanova et al., 1998), or (b) R or Quad/LoD tree files (eg. Gruber, 1998, 1999; Reddy et al, 1999a)

*(c) Real-time navigation***.** Visualization and navigation in real time is the ultimate goal. It generates therefore to all the mentioned problems and is of course closely connected to the DataBase structure. Especially from the photogrammetric point of view, and besides the problem of large databases, it acquires another special meaning and imposes a special requirement: it is quite meaningful to navigate in true-world-coordinates and be able to have a pointing device (eg. mouse) to get back true positions, dimensions etc., together with their accuracy indicators. This means that, besides all other problems, navigation, to us, is connected to geo-referencing and metadata inclusion as well.

(d) DataBase structures. The structuring of DataBases (especially the very large ones), in order to be able to support solutions for effective real-time visualization through texture mapping and LoD generation, is quite complex issue. It becomes even more complex once we introduce the requirements of geo-referencing and metadata inclusion. Closely connected to DataBase structure, although is not a problem of structure itself, is the problem of maintaining the accuracy of the original data. This has to do with the internal single-precision some systems use, in order to be able to coop timely with the data with mere integer numbers. From the point of view of Photogrammetry double precision is required.

For fast data access Quad-tree or R-tree techniques and dynamic LoD representations have been suggested (eg. Wiggenhagen, 2000; Zlatanova et al, 1998). Tree-structures (with their useful characteristics of Scalability, Multiresolution hierarchy, and Progressive transmission) are reported to better suit for representing the multi-resolution textures (LoD's) in contrast to image pyramids (Karner et al, 2001).

Good examples of effective database structures are the often called "Simulation packages" or "Paging Software" (eg. TerraVista (URL14) or OpenFlight (URL15)). Unfortunately, they have no analytical capabilities and what they do is to manipulate the data of a database in an intelligent manner and convert it into a new format, that enables the user to visualize it. The ability to show this database is left to, sometimes freeware, run-time (eg. VizMAP (URL16)) applications.

*(e) Geo-Referencing***.** Although we set this problem from our photogrammetric perspective, it is not a requirement of Photogrammetry only. All CAD and GIS systems offer the ability to maintain the coordinate system to which the original data refer. In the vast majority of the visualization systems though, this is not the case, since they are using simple Cartesian Local coordinate systems. Unless we are able to define our data's coordinate system, we will not be able to get real-world positions and dimensions, meaningful accuracy measures, and proper multi-resolution data fusion. So, geo-referencing is an absolute necessity to everybody dealing with real-world objects.

There many visualization packages which offer geo-referencing of the data. Apart from these specialized tools, however, the majority of the usually used visualization packages do not allow the user to define its own coordinate system. VRML is one sound example of this, and it constitutes a major problem, since there is a big number of users of VRML. Therefore introducing geo-referencing in VRML (we refer to the recent initiative towards GeoVRML) is an important step towards our (photogrammetric) needs.

Capabilities addressed by GeoVRML(URL17) are: (a) *Coordinate Systems* - Ability to embed coordinates directly into a VRML file; (b) *Precision* – Ability to extend the VRML97 single precision in order to enable sub-mm positional accuracies; (c) *Scalability* - Scalability to manage large, multi-resolution data; (d) *Metadata* - Ability to specify metadata describing geographic objects; (e) *Animation* - Ability to interpolate within coordinates for definition of animations with respect to key points on the earth surface; (f) *Introspection* - Ability to discover the coordinates of any georeferenced point; (g) *Navigation* - Support for navigation schemes, as eg. the issue of elevation scaled velocity.

(f) Metadata inclusion. Origin and time-tag of original data, processing method, originator, quality indicators, etc. are very important information to be left aside when the data will enter a visualization tool. The requirement for inclusion of metadata as well as the way it can be implemented for easy user parsing is a very important one.

4. VISUALIZATION IN PHOTOGRAMMETRY

4.1 What Has Been Achieved

Visualization efforts in Photogrammetry do not have a long history. In the beginning of 90's the first photogrammetric attempts were mainly focused on the use of CAD software and the generic visualization tools they had to offer. Most of the research efforts at that time were concentrated to automating the data acquisition and processing through Digital Photogrammetry concepts, thus little attention was paid on how to add value to the data. The major concern was the data themselves. It is important to note that, at that time, most of the visualization efforts were aiming to monitor and improve the quality of the acquired data. Thus, early visualization examples were showing error ellipsoids, residual surfaces, etc.

Soon it was realized that the acquired data should be delivered to the biggest possible user group and presented in an attractive manner. This gave rise to promising 3D visualization examples, although there were only two choices: either use the generic tools of the existing CAD packages or use high-end proprietary software with the necessary (again high-end) hardware. But the aim was not achieved since both tracks were not approaching or they were not appealing to the end-user. It is also worth noting that besides the CAD packages, the DPW's were not proud of their visualization capabilities either.

Visualization applications in Architecture (eg. Hirschberg, 1996; Freudenreich, 1996), Archaeology (eg. Doneus, 1996) were the first to cross the discipline and reach out. The first applications were mostly using CAD or CAD-supported generic visualization tools. Image rectification and stapling to facades was almost used exclusively. The visualization of the 3D objects and the draped images was achieved through basic animations and fly-overs, exporting to popular AVI's and MPEG's.

At the same time, it became apparent that image-based rendering can mask model irregularities or inefficiencies, and can anyway offer a powerful and cost-effective tool for visualization. Low-end software (like 3D-Builder, PhotoModeler, etc) provide adequate visualization tools for low-cost projects and not very demanding results.

During the last 5 years, photogrammetrists are increasingly more attracted by web-based visualization. Their research is motivated by the fact that an increasing number of free-ware viewers make available visualization results to the extent possible. Questions of standardization, efficiency and productivity remain the standard questions, but applications are showing remarkable imagination, and in a number of publications and presentations, researchers have become major proponents of using VRML and QTVR output (see interesting examples in Sakamoto et al , 2001; Ruther et al, 2001; Grün et al, 2001; Yasuda et al, 2001; Gemenetzis et al, 2001; or Ogleby, 2001a, b among many others)

4.2 What is to be Expected

4.2.1 Visualization and Information Retrieval

Many visualization packages have the ability to link additional information, apart from geometry and texture, to the 3D model. This information can be in the form of text documents, sound sequences, movies or even other VR scenes. These possibilities greatly enhance and widen the applicability of visualization tools and shorten the gap between visualization and GIS technology. New applications like distributed visualizations, interactive simulations for education, virtual museums, and more arise from that.

For example, VRML gives the ability to the developer to define some key-positions (anchor nodes) using viewpoints and then an automatic fly-through the scene can be animated in real-time. Using this possibility the interactivity is not limited any more to the purely VRML scene but also external systems, as for example databases, can be connected. In this way, the VRML model can be used as kernel of an interactive spatial information system (see eg. Dorffner L., 1996, 1999). Generally, there are two different classes of interactive queries inside an Information System: (1) Getting information about a selected object and (2) Searching for objects which satisfy specific requirements. The first class of queries is already implemented inside the VRML specification, and can be used by an assignment of an action to a geometric object. Some of the possible actions are: (a) hyperlinks to HTML pages, (b) portals to other VRML scenes, or (c) execution of a Java Applet in the web browser.

Similarly, using QTVR, each panorama and object can represent a node of a complex scene where the nodes are connected together by creating hot-spots on the images. Multimedia techniques are available for linking to different URLs. An interesting archaeological application can be found in (Bitelli et al, 2000), where links to text, information sheets and video clips are inserted in the virtual scene. The second class of queries is not implemented inside VRML and can only be programmed (eg. with Java Applets and EAI's). An example of such an approach can be found in (Landes, 1998).

Developments of this kind, up to now, are only demonstrated the possibilities of merging visualization with Information Systems. The major contribution of their research efforts has been to show the utility of different approaches. It is anticipated, however, that future progress in this respect will be very rewarding. But there are currently major research issues involved: data formats, large database structures, timely information retrieval modules, intelligent query modules, etc.

Recently, 3D city modelers, like CC-Modeler (ETH-Zurich, eg. Gruen and Wang, 1998), ObEx (University of Bonn, eg. Guelch et al, 1999), and University's of Stuttgart efforts (eg. Brenner, 1999), have shown that even seamless visualization is a major problem. Therefore, it seems that an important key to this work will be our ability to coop with large datasets.

4.2.2 Visualization and measurement acquisition

In addition, also measurement tools (co-ordinates, orientations, distances, etc.) can be added using external modules. In a demonstration, Zischinski (Zischinski et al, 2000) uses a EAI (External Authoring Interface) interface that allows programmers to establish a connection between a web page and an embedded VRML browser window, thus providing a possibility to manipulate the VRML scene depending on user requests on the web page. In a first simple example presented in (Bitelli et al, 2000), this is accomplished by inserting a link to a Web page where a rectified image is displayed. With a Java applet and a simple procedure, it becomes possible to measure the distance between points or the area of closed polygons selected with the mouse. Thanks to the universality of Java language, this type of application can be used on any platform and any user of the Internet site, exploring the virtual scene, can perform metrical analyses on the objects using only the resources of the web browser.

Although such attempts are only in their initial steps, they demonstrate the possibility of using the visualization tools in Web for performing measurements. The rationale behind this, is to use the widely accessible Web to perform remotely measurements on photogrammetrically derived 3D products, widening thus the user base of such products. Measuring in stereo is probably not the major problem here, since the photogrammetric procedures have already delivered the final output. However, accuracy indicators, metadata inclusion and geo-referencing are the major issues. The author's speculation is that the current development of visualization tools allow much more space for such developments than the one used already. If this will accomplished then one of the major aims of photogrammetrists will be met.

4.2.3 Visualization and Web-based Photogrammetry

A comparative analysis of the development of Digital Photogrammetry offers a good view-point to speculate on future developments. The promise of lower-cost hardware has always been a major driving force in system development. It is very logical to extent this to the use of an almost zero-cost hardware/software on web-based photogrammetric procedures.

Earlier attempts on developments of Web-based Photogrammetry were aiming mainly to education (Höhle, 1998), (Grussenmeyer et al, 1999, Drap et al, 2000). Sarjakoski (Sarjakoski et al, 1998) sets nicely the functional requirements the developed tools should meet to be considered Web-based Photogrammetry. In summary, they should be: (a) based on a widely used web-browser; (b) able to browse a set of accessible images and select one or more; (c) able to select the working area from an overview image and then choose the suitable resolution for measurements; (d) able to provide stereo-viewing and stereo-measuring; (e) able to minimize the network traffic for timely retrieval of data; (f) able to provide data and output storage at the user's end.

All these requirements are easier to say than done. There are major developments required and probably the current technology is not yet available. Currently, major disadvantages are Loading and execution time, instability of Java, and Java security restrictions, that prohibits read/write operations on client disks. Besides, however, the apparent current difficulties, it is believed that the development of new Internet-based tools will gives new chances to Web-based Photogrammetry.

REFERENCES

Boochs, F., C. Garnica and F. Wolter, 1998, *Determination and interactive visualization of 3D objects*, IAPRS, Vol. 32, Part 5 "Real-Time Imaging and Dynamic Analysis", Hakodate, 1998, pp. 316-322.

Boulanger, P. and J. Taylor, 2000, *The Virtual Museum - Data generation and Visualization,* IAPRS, Vol. XXXIII, Special Sessions, Supplement, Amsterdam 2000, pp. 4-9.

Brenner, C., 1999, *Interactive modelling tools for 3D building reconstruction,* Photogrammetric Week'99 Proceedings, Fritsch/Spiller eds, Wichman, pp. 23-34.

Chen, S.E and L. Williams, 1993, *View interpolation for image synthesis,* Proc. of SIGGRAPH '93, pp. 279-288.

Debevec, P., 1999, *Introduction to Image-Base Modeling, Rendering and Lighting,* SIGGRAPH 99 Course #39.

Dorffner, L., 1996, *A new approach for spatial measurement of dynamical processes,* IAPRS, Vol. XXXI, Part B3, Com. III, Vienna, 1996, pp. 135-138.

Dorffner, L., 1999, *Using photo-models as a basis for an interactive 3-dimensional Information System,* Proc. of XVII CIPA Symposium, Recife, Brazil, 3-6 Oct. 1999.

Drap, P., and P. Grussenmeyer, 2000, *A digital photogrammetric workstation on the WEB,* ISPRS Journal of Photogrammetry & Remote Sensing, vol. 55, pp. 48-58.

El-Hakim, S., C. Brenner, and G. Roth, 1998, *An approach to creating virtual environments using range and texture,* ISPRS Commission V Symposium, Hakodate, Japan, June 1998..

Freudenreich, P., 1996, *Photorealistic presentation of the Palais Grand Ducal based on photogrammetric recording,* IAPRS, Vol. XXXI, Part B5, Com. V, Vienna, 1996, pp. 173-177.

Gemenetzis, D., H. Georgiadis and P. Patias, 2001, *Virtuality and Documentation: Recreating the Byzantine Heritage,* Proc. of International Workshop on Recreating the Past -Visualization and Animation of Cultural Heritage, Ayutthaya, Thailand, 2001.

Gruber, M., 1998, *The Cyber-City concept. From 2d GIS to the hypermedia database,* Proceedings of UM3'98, International Workshop on Urban Multi-media/3D Mapping, Tokyo, Japan, June 8-9,1998, pp. 47-54.

Gruber, M.,1999, *Managing Large 3D Urban databases,* Photogrammetric Week'99 Proceedings, Fritsch/Spiller eds, Wichman, pp. 341-349.

Gruen, A. and S. Beutner, 2001, *The geoglyphs of San-Ignacio - New results from the Nasca project,* Proc. of International Workshop on Recreating the Past -Visualization and Animation of Cultural Heritage, Ayutthaya, Thailand, 2001.

Gruen, A. and X. Wang, 1998, *CC-Modeler: A topology generator for 3-D city models,* IAPRS, Vol. 32, Part 4 "GIS-Between Visions and Applications", Stuttgart, 1998.

Grussenmeyer, P., P. Drap, M. Koehl and J-Y Blaise, 1999, *TIPHON and ARPENTEUR:Simple photogrammetric software packages for stereoplotting,* Proc. of ISPRS/WG V/I, V/5 Workshop, Thessaloniki GR,.

Guelch, E., H. Mueller and T. Laebe, 1999, *Integration of automatic processes into semi-automatic building extraction,* IAPRS vol. 32, Part 3-2W5, Munich.

Guerra, F., and C. Balletti, 1999, *Survey and Virtual reality: the Guggenheim museum in Venice,* Proc. of ISPRS/WG V/I, V/5 Workshop, Thessaloniki, Greece.

Heckbert, P and M. Garland, 1997, *Survey of polygonal surface simplification algorithms,* Multiresolution Surface Modelling Course #25, SIGGRAPH '97.

Hirschberg, U., 1996, *Object-oriented data-integration between Digital Architectural Photogrammetry and CAAD,* IAPRS, Vol. XXXI, Part B5, Com. V, Vienna, 1996, pp. 237-242.

Hoppe, H., 1996, *Progressive meshes,* Proc. Of SIGGRAPH '96, pp. 99-108.

Kang, S.B., 1997, *A survey of image-based rendering techniques,* Techn. Report CRL 97/4, Cambridge Research Lab, Digital Equipment Corp..

Kang, S.B., 1998, *Geometrically valid pixel reprojection methods for novel view synthesis,* ISPRS Journal of Photogrammetry & Remote Sensing, vol. 53, pp. 342-353.

Karner, K., J. Bauer, A. Klaus, F. Leberl and M. Grabner, 2001, *Virtual Habitat: Models of the urban outdoors,* Third International Workshop on “Automatic Extraction of Man-Made Objects from Aerial and Space Images”, 10-15 June 2001, Ascona. .

Karras, G., Patias, P., Petsa, E., Ketipis, K., 1997, *Raster projection and development of curved surfaces,* Intern. Archives of Photogram. & Remote Sensing, Vol. XXXII, Part 5C1B, Göteborg, pp. 179-185.

Landes, S., 1998, *Impact on 3D modelling from the design of a web-based 3D Information System,* Archives of Photogrammetry & Remote Sensing, Vol. XXXII, Part 5, Hakodate, pp. 339-343.

Luebke, D., 1997, *A survey of polygonal simplification algorithms,* Techn. Report TR97-045, Dept. of Computer Science, University of North Carolina, Chapel Hill.

McMillan, L., and G. Bishop, 1995, *Plenoptic modelling: An image-based rendering system,* Proc. Of SIGGRAPH '95, pp. 39-46.

Neyret, F. and M-P Cani, 1999, *Pattern-based texturing revisited*, Computer Graphics, Aug. 1999, pp. 235-242.

Ng, K., V. Sequeira, S. Butterfield, D. Hogg, and J. Gonçalves, 1998, *An integrated multi-sensory system for photo-realistic 3D scene reconstruction,* IAPRS, Vol. 32, Part 5 "Real-Time Imaging and Dynamic Analysis", Hakodate, 1998, pp. 356-363.

Ogleby, C., 2001a, *The ancient city of Ayutthaya-Explorations in virtual reality and multi-media*, Proc. of International Workshop on Recreating the Past -Visualization and Animation of Cultural Heritage, Ayutthaya, Thailand, 2001.

Ogleby, C., 2001b, *Olympia - Home of the ancient and modern Olympic Games. A VR 3D experience*, Proc. of International Workshop on Recreating the Past -Visualization and Animation of Cultural Heritage, Ayutthaya, Thailand, 2001.

Pollefeys, M., R. Koch, R. Vergauwen and L. Van Gool, 1999, *An automatic method for acquiring 3D models from photographs: Applications to an archaeological site,* Proc. of ISPRS/WG V/I, V/5 Workshop, Thessaloniki, Greece.

Reddy, M., Y. G. Leclerc, L. Iverson, N. Bletter, and K. Vidimce, 1998, *Modeling the Digital Earth in VRML,* Technical Note 559, AI Center, SRI International, 333 Ravenswood Ave., Menlo Park, CA 94025, November 1998.

Reddy, M., Y. G. Leclerc, L. Iverson, and N. Bletter, 1999a, *TerraVision II: Visualizing Massive Terrain Databases in VRML*, IEEE Computer Graphics and Applications (Special Issue on VRML), vol. 19, no. 2, pp. 30-38.

Reddy, M., Y. G. Leclerc, N. Bletter, and K. Vidimce, 1999b, *Modeling the Digital Earth in VRML*, Proceedings of SPIE - The International Society for Optical Engineering, vol. 3905..

Reddy, M., 1999c, *Specification and Evaluation of Level of Detail Selection Criteria*, Virtual Reality: Research, Development and Application, vol. 3, no. 2, pp. 132-143.

Ruther, H., C. Fraser, A. Gruen and T. Buehrer, 2001, *The recording of Bet Giorgis, a 21st century rock-hewn church in Ethiopia*, Proc. of International Workshop on Recreating the Past -Visualization and Animation of Cultural Heritage, Ayutthaya, Thailand, 2001.

Sakamoto, K. and H. Chikatsu, 2001, *Efficient recreation of the past objects and visual simulation*, Proc. of International Workshop on Recreating the Past -Visualization and Animation of Cultural Heritage, Ayutthaya, Thailand, 2001.

Sarjakoski, T., and P. Myllyniemi, 1998, *Webtop Photogrammetry- A tool for distributing photogrammetric imageries and knowledge*, IAPRS, Vol. XXXII, Part 4, Com. IV Symposium, Stuttgart, pp. 505-510.

Segal, M., and P. Haeberli, 1993, *Texture Mapping As A Fundamental Drawing Primitive*, Proc. Of the fourth Eurographics Workshop On Rendering, June 1993, pp. 259-266.

Sequeira, V., K. Ng, E. Wolfart, J. Goncalves, and D. Hogg, 1999, *Automated reconstruction of 3D models from real environments*, ISPRS Journal of Photogrammetry & Remote Sensing, vol. 54, pp. 1-22.

Soucy, M. and D. Laurebdeau, 1996, *Multiresolution surface modelling based on hierarchical triangulation*, Computer Vision and Image Understanding, vol. 63, no. 1, pp. 1-14.

Spann, J. and K. Kaufman, 2000, *Photogrammetry using 3D graphics and projective textures*, IAPRS, Vol. XXXIII, Part B5/1, Com. V, Amsterdam 2000, pp. 748-755.

Szeliski, R., 1996, *Image mosaics for Virtual Environments*, IEEE Computer Graphics and Applications, vol. 16, no. 2, pp. 22-30.

Visnovcova, J., L. Zhang and A. Gruen, 2001, *Generating a 3D model of the Bayon tower using non-metric imagery*, Proc. of International Workshop on Recreating the Past - Visualization and Animation of Cultural Heritage, Ayutthaya, Thailand, 2001.

Wiggenhagen, M., 2000, *Development of real-time visualization tools for the quality control of digital terrain models and orthoimages*, IAPRS, Vol. XXXIII, Part B3, Com. 3, Amsterdam 2000, pp. 987-993.

Woodhouse, N., S. Robson and J. Eyre, 1999, *Some roles of vision metrology and associated visualization tools in structural testing and engineering experimentation*, Proc. of ISPRS/WG V/I, V/5 Workshop, Thessaloniki, Greece.

Zlatanova, S. and M. Gruber, 1998, *3D urban GIS on the Web: data structuring and visualization*, IAPRS, Vol. 32, Part 4 "GIS-Between Visions and Applications", Stuttgart, 1998, pp. 691-699.

URL1:http://www.opengis.net/gml/01-029/GML2.html:GML page

URL3:http://www.opengis.net/techno/specs.htm#abstract:OpenGIS Simple Feature Specification

URL4:http://www.microsoft.com/directx and
http://www.msdn.microsoft.com/nhp/default.asp:DirectX page
URL5:http://www.clr.utoronto.ca/polytrim.html:CLRview / PolyTRIM page
URL6:http://www.tgs.com/pro_div/oiv_main.htm:TGS OpenInventor C++
URL8:http://www.erdas.com/software/main.asp:ERDAS IMAGINE VirtualGIS
URL9:http://www.pcigeomatics.com/:PCI page
URL10:http://www.shapequest.com:ShapeCapture page
URL11:http://www.photomodeler.com/vrml.html:Photomodeler page
URL12:http://www.ai.sri.com/:SRI's TerraVision II page
URL16:http://www.cg2.com/out-going/AuditionInstall.exe:VizMAP page
URL13:http://www.multigen.com/oflight.htm:OpenFlight format page
URL14:http://www.terrex.com/www/pages/products/tvbuilderpage.htm:TerraPageformat page
URL13:www.terrex.com:Terrex page
URL17:http://www.geovrml.org/1.0/:GeoVRML page
URL7:http://www.rsinc.com/idl/:Research Systems page – IDL info
URL2:http://www.w3.org/:The World Wide Web Consortium home page.

CONTACTS

Petros Patias
The Aristotle University of Thessaloniki, Greece
Dept. of Cadastre, Photogrammetry and Cartography
Univ. Box 473
Thessaloniki, GR-54124
GREECE
Tel. + 30 2310 99 61 16
Fax +30 2310 99.61 28
Email: patias@topo.auth.gr