State-of-the-Art of Digital Photogrammetric Workstations for Topographic Applications[1]

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Abstract

Digital Photogrammetric Workstations (DPWS) have become a major focus of research within the photogrammetric community in the last few years due to an increasing availability of digital imagery and a revolutionary hardware progress in computer science. Today more than a dozen DPWS are offered on the market and they are on the verge of replacing the analytical plotter as the main photogrammetric instrument for evaluating imagery.

This paper presents the state-of-the-art of DPWS. A DPWS is the main component of a Digital Photogrammetric System (DPS). A DPS is defined as hardware and software for deriving input data for Geographic Information Systems (GIS) as well as for Computer Aided Design (CAD) systems and other photogrammetric products from digital imagery using manual and automatic techniques. Besides the DPWS itself, a DPS also includes A/D and D/A converters for the imagery (digital cameras, film scanners, and output devices for producing film and paper hardcopies).

First, design issues of a DPWS are addressed. Then, the question of automation versus interaction is discussed, and it is pointed out where automation is possible in the chain of processing digital imagery. Subsequently, a classification of the different kinds of DPWS according to the products which can be derived is given. Then first experiences and results obtained by civil mapping organizations involved in digital photogrammetry and using DPWS are described. Finally, requirements for a broader use in practice and trends for further development in digital photogrammetry and in DPS are pointed out.

Introduction

Digital photogrammetry is an information technology used to derive geometric, radiometric, and semantic information about objects in the three-dimensional (3D) world from 2D digital images of these objects. It has become a major focus of research in the last decade, although first research activities date back nearly 40 years (Rosenberg, 1955; Sharp *et al.*, 1965). A number of reasons can be stated for this increasing interest. The most important of these are that digital image data have become available on a routine basis, that due to revolutionary progress in computer science the possibility to process these data has become a reality, and that digital photogrammetry has the potential for automating large parts of the photogrammetric processing chain and thus for providing quick response times. Also, the hope for new products, for new markets, and for cost savings through cheaper equipment and less qualified labor have played an important role in the development of digital photogrammetry.

Methods to generate object descriptions from visual images have also been investigated in computer vision. While its roots lie in close-range applications, an increasing body of work deals with aerial and satellite images for topographic applications (see, e.g., Huertas and Nevatia, 1988; McKeown, 1988; Venkateswar and Chellappa, 1990; Quam and Strat, 1991; Price and Huertas, 1992). In contrast to computer vision, intermediate results in the mapping process such as digital terrain models (DTM) or orthoimages play an important role on their own in photogrammetry. However, the ultimate goal of both disciplines, the complete automation of the mapping process, is identical, and the ways to achieving this aim are becoming more and more similar. Therefore, it seems appropriate to deal with digital photogrammetry and computer vision as one discipline, at least when applied in the mapping domain, and no further distinction will be made in the following. Thus, instead of talking about a digital photogrammetric workstation (DPWS), one could also talk about a computer vision workstation.

This paper presents the state-of-the-art of the tool for processing digital imagery, the DPWS. A DPWS is the main component of a Digital Photogrammetric System (DPS) (Figure 1). First concepts for DPWS and DPS date back to the early 1980s (Sarjakoski, 1981; Case, 1982), and today a large number of DPS vendors can be found on the market. A DPS is defined as the hardware and software for deriving input data for Geographic Information Systems (GIS) as well as for Computer Aided Design (CAD) systems and other photogrammetric products from digital imagery using manual and automatic techniques (Ebner *et al.*, 1990). Besides the DPWS itself, a DPS also includes A/D and D/A converters for the imagery (digital cameras, film scanners, and output devices for producing film and paper hardcopies). Recent discussions on different aspects of DPS can be found in Dowman (1990; 1991a), Helava (1991a; 1991b), Leberl (1991, 1992), and Dowman *et al.* (1992).

In the next section, design issues of a DPWS are addressed. Then, the question of automation versus interaction is discussed, and it is pointed out where automation is possible in the chain of processing digital imagery. In the fourth section, a classification of the different kinds of DPWS accord-

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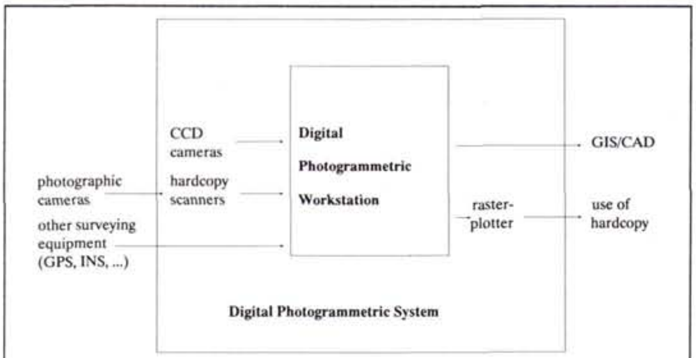

Figure 1. DPS and DPWS.

ing to the products which can be derived is given. The fifth section describes first experiences and results obtained by civil mapping organizations involved in digital photogrammetry and using DPWS. In the last section requirements for a broader use in practice and trends for further development of DPWS are pointed out.

Design Issues of a DPWS

A trend could be observed in recent years to convert general computer workstations into DPWS with only limited or no changes in hardware. In this case, special and expensive components are omitted and the software becomes more portable. However, a closer look at existing DPWS reveals that the complete elimination of special hardware has not yet been achieved, mainly due to the high demands on image handling and display. However, if the DPWS is used for special purposes only (e.g., for batch processes such as orthoimage computation), if the accuracy requirements are less demanding (e.g., in thematic mapping, planing, and environmental applications), or if the DPWS is mainly used for viewing and verification of the results rather than for interactive measurement (e.g., in automatic DTM generation), a DPWS with only commercial off-the-shelf components can be (and has been) realized already today.

A DPWS for topographic applications should be equipped with the following hardware components (see Figure 2):

- a fast central processing unit (CPU) with sufficient main memory;
- a graphics subsystem, including a true color (24-bit-per-pixel) image memory, a non-destructive overlay, and a fast processing unit for on-line computations (e.g., continuous subpixel roam, continuous zoom) and display;
- a high resolution stereo color monitor;
- fast busses to ensure high data transfer rates;
- a comfortable 3D measurement device (3D mouse); and
- high capacity disks, network access, keyboard, printer, backup, and other peripherical devices.

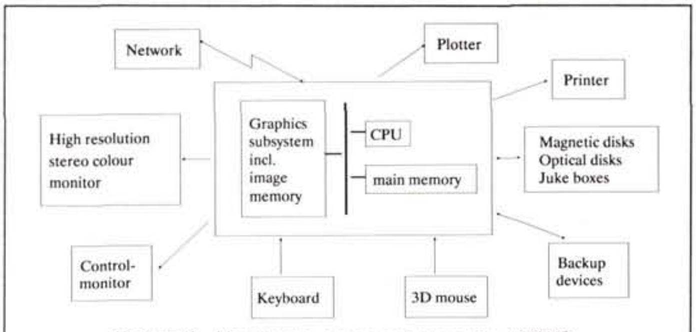

Figure 2. Hardware components of a DPWS.

Considering the amount of data which have to be processed (typically, an aerial image represents one to several hundred megabytes) and the complexity of the computations to be carried out, some of these items go without explanation. Others deserve a closer look. For instance, a fast connection via network is very important if the different tasks of the photogrammetric processing chain are to be carried out on different DPWS (but not necessarily by different operators), or if several operators work on the same project and data are shared.

In the following, three issues related to the user interface and being somewhat special to photogrammetry (stereo viewing, interactive measurement, and subpixel accuracy) are discussed in more detail.

Stereo viewing is indispensable for most mapping purposes. The necessary image separation can be achieved through

- spatial separation (two monitors or a split screen monitor, both equipped with optics),
- radiometric separation (anaglyph method or polarization), or
- temporal separation (alternate display of the two images).

In nearly all existing DPWS, temporal separation in connection with polarized light is used in one of two ways. In both cases, the vertical is only half of the horizontal resolution due to limitations of the analog electronics[2]. In the first case (see Figure 3), a polarization screen is mounted in front of the monitor. It polarizes the emitted light in synchronization with the display of the images. The operator views the images stereoscopically using a set of passive polarizing glasses. In the second case, the polarization screen is integrated into the glasses, which then become active. The synchronization is assured by means of an infrared beam.

In the first solution, the monitor must be equal in size to the polarization screen. Simultaneous stereo viewing is possible on any number of monitors set up next to each other and controlled by separate DPWS. In the latter solution, the same equipment can be used for any monitor without size limitations. However, flickering can occur if somebody wearing the active glasses looks at another (mono or stereo) monitor. This effect is due to synchronization problems between the two monitors. In both cases, color superimposition of image and vector data is possible. Multiple viewers can see the same scene while freely moving their heads. For comfortable stereo viewing, a minimum refresh rate of 60 Hz per image (120 Hz for the monitor) is necessary, and the dynamic range (the ratio between the amount of light received by the eyes when an image is visible and invisible) must be as high as possible. Also, there should be a minimal loss of overall brightness due to the image separation.

For interactive stereo measurement in photogrammetric production work, a comfortable 3D measurement device is to be preferred to the combination of a 2D mouse and a trackball for reasons of accuracy, stability, and ease of use. In or-

[2]Recently, hardware capable of displaying stereo imagery at full horizontal and vertical resolution has appeared on the market. This hardware will probably be used in DPWS in the near future.

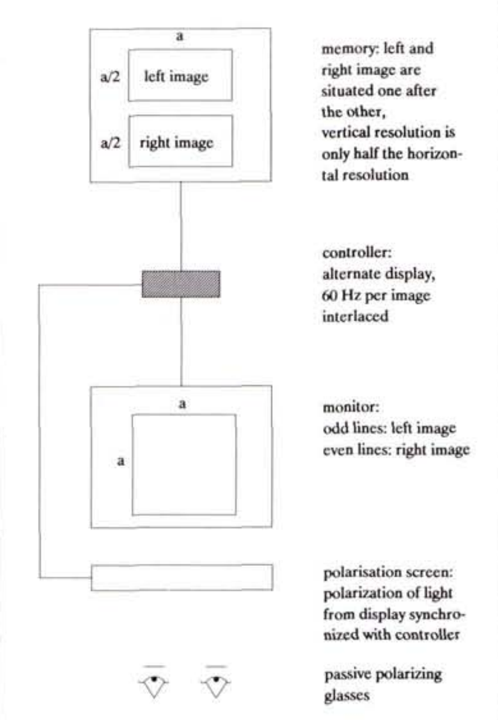

Figure 3. Stereo viewing in a DPWS.

der to move the cursor relative to the images, two possibilities exist: either the cursor is moved in front of fixed images or the images are roamed behind a fixed cursor situated in the middle of the screen. The first case is easier and cheaper to realize, but the stereo impression is lost when new parts of the images must be displayed. This also results in a certain time delay. The latter is by far more comfortable for a human operator, because he can freely move through the whole image in the same way as in an analytical plotter. Care has to be taken, however, that images and superimposed graphics can be moved smoothly and simultaneously at a reasonable speed.

In both cases, subpixel accuracy can be achieved during interactive measurement. If the images are fixed, a zoom function enlarges the image pixels, but not the cursor. The cursor is then moved from one screen pixel to the next. This is equivalent to moving the cursor to only a fraction of the original image pixel. If the cursor is fixed, the zoomed images are roamed screenpixel by screenpixel. Alternatively, the original images are roamed by a fraction of the image pixel only using on-line resampling with or without zoom. The same procedure must be applied to the superimposed graphics.

It is the ability for accurate interactive stereo measurement which differentiates the DPWS from a general purpose computer. Today, extensive use of a powerful graphics subsystem, including a large image memory, must be made due to the required high speed for roaming imagery and graphics and due to the size of the images. However, it is feasible that in the future the graphics subsystem can be emulated in software and a standard display card can be used. This requires above all a powerful CPU with a real-time operating system, fast main memory chips, and fast internal busses for data transfer between CPU, main memory, and display card.

Automation versus Interaction

While the design issues discussed in the previous section are important, the heart of a DPWS lies in the implemented software. Analytical plotters are already equipped with a whole range of program packages related mainly to positioning the measuring mark (cursor) at given locations in image or in object space and to manual vector data acquisition. However, the use of digital imagery offers the potential for automating substantial parts of the processing chain of digital photogrammetry. The benefits of automation are results which are not biased by the human operator, faster turn-around times, less expensive equipment (because the requirements for comfortable, fast, and accurate image display and measurement facilities are costly to fulfill), and, thus, cost-effective solutions. However, in the foreseeable future there is no way to derive topographic information completely automatically from aerial and satellite imagery. Therefore, we will take a closer look at the different tasks of the mentioned processing chain and show where automation is possible (see Heipke (1993)). Such tasks are the orientation of the imagery (interior, relative, absolute), point transfer for aerotriangulation, DTM generation, geometric image transformations (orthoimage computation, generation of epipolar images and perspective views, etc.), feature extraction, and orthoimage map generation.

Automation can take the form of completely automatic batch processes or semi-automatic interactive processes. Batch processes are possible for interior and relative orientation, point transfer, DTM generation, and geometric image transformation. In the latter case, a set of projection equations is applied to every pixel in a predetermined way. For the other tasks, image matching algorithms play the essential role in obtaining a solution.

DTM generation is subject to blunders, especially in areas of low or repetitive texture. Additional problems can occur in large-scale imagery due to occlusions and height discontinuities, e.g., in built-up areas or forests. Thus, a verification step is required after the batch process. While it is desirable and in some cases also feasible to add a self-diagnosis module to the matching algorithms, the verification step is normally carried out by the human operator. Here, the DPWS comes into play, providing a means for visualization of the results and for interactive corrections. Manual point-wise quality control can be performed, if the cursor is locked onto the derived DTM, while the operator inspects the images stereoscopically. If available, a color coded index of the matching quality (figure of merit), superimposed onto the imagery, gives clues for detecting areas of matching success and failure. The DTM grid, or contours derived from the DTM, can also be superimposed onto the images in stereo. At the request of the operator, orthoimage stereo mates can be generated (locally and in near real time) to give an even better impression of the quality of the results.

It is not sufficient to only identify areas of bad matching in the DTM, but the results must also be corrected. This step is crucial for successful automatic DTM generation. For this task, semi-automatic processes can be used. After manually selecting points, profiles, or areas to be corrected, the operator provides a Z coordinate close to the actual terrain, and then the system generates a new result. This result in turn is visualized, verified, and corrected if necessary. If enough computer power is available, it is even feasible to incorporate point-wise interactive matching into the real-time loop of the DPWS. In this case, while the operator moves through the images, the measuring mark always sits on the terrain and a Z coordinate is automatically and instantaneously provided for every XY position.

Another example of semi-automatic processes is the measurement of the image coordinates of a point with given coordinates in one image. This procedure can be applied when measuring image coordinates of tie points or ground control points. In one image the exact position is provided by the operator, and then the image coordinates of the point in the other image(s) are found automatically.

Semi-automatic processes are also used in feature extraction. The operator can provide attributes for the relevant feature along with an initial position or shape; the system then finds the exact location of the feature. Road-following algorithms have been designed along these lines (Quam and Strat, 1991); the use of snakes for the extraction of house contours is another example (Kaas *et al.*, 1987; Gülch, 1989). These processes can also be carried out in such a way that the algorithm automatically suggests candidates for a point to be measured (e.g., a tie point), for a certain feature class, or for a place in the map where a name could be placed. These suggestions are verified and further processed by the human operator. The preprocessing can vary from interest operators or simple image segmentation algorithms to complex image analysis procedures. It must be said, however, that, from a practical point of view, most of these algorithms are not yet mature enough to be used in a commercial DPWS.

In summary, it can be observed that the automation of parts of the photogrammetric processing chain has made substantial progress in the last few years. However, the algorithms need to be implemented in an interactive environment, such as a DPWS. The DPWS is equipped with the necessary photogrammetric software together with a comfortable user interface. The human operator provides initial values for the algorithms, verifies and corrects the automatically obtained results, and performs additional measurements manually.

Classification of DPWS

In this section, a classification of existing commercial DPWS will be given according to the products which can be derived (Helava, 1988; Dowman, 1991a). The classes are stereo DPWS, mono DPWS, aerotriangulation DPWS, DTM DPWS, and orthoimage DPWS. For each class, companies producing such DPWS are listed including an appropriate reference. Most systems have interfaces to existing scanners and raster plotters, and thus can be extended to a DPS. Recently, a large number of companies offering digital image processing, remote sensing, and/or GIS software have added tools for photogrammetric image processing to their products. These are then also considered a DPWS. The presented list is not claimed to be complete (which, by the way, would be a very difficult task due to the rapid changes in the market). Also, the development status (design or production) of the systems is not always clear. It was decided to exclude university systems because they mainly serve research interests and, in general, have not reached an operational stage. Also, systems which are no longer available on the market are not listed.

It should be noted that in commercial DPWS only two tasks of the above mentioned processing chain (DTM generation and orthoimage computation) have been cast into automatic batch processes. These are precisely the tasks which are relatively easy to automate as well as being time consuming. Thus, time and cost savings can be expected. Semi-automatic processes are only available for point transfer and DTM correction. This shows that the capabilities of DPWS are far from being exhaustively used today.

Stereo DPWS

These systems are used for interactive stereo plotting. They can be further classified into high end and low end systems. The high end systems allow for the generation of the complete range of photogrammetric products; generally include aerotriangulation, DTM, and orthoimage DPWS; and are on the verge of replacing the analytical plotter in the future. Interactive measurement of image coordinates is done with a fixed cursor in the middle of the screen, while the images are roamed according to the operator's movement of the 3D mouse. Examples are

- Autometric Softplotter (Autometric, Company Information, 1994);
- DAT EM Digitus (DAT EM, Company Information, 1993);
- Intergraph ImageStation (Kaiser, 1991);
- ISM Digital Image Analytical Plotter (ISM, Company Information, 1993);
- Leica Digital Photogrammetric Workstation DPW 710, 750, and 770 by Helava (Miller *et al.*, 1992);
- MacDonald Dettwiler Topographic Data Base Revision System (Ahac *et al.*, 1992);
- Matra MS2I Traster T 10 (Cruette, 1991); and
- Zeiss PHODIS ST (Mayr, 1993).

The low end systems are less expensive, but have a limited functionality. Some are specialized for satellite imagery. They are often used outside photogrammetry where, in general, the accuracy requirements are somewhat relaxed. Existing systems include

- Leica/DVP Digital Video Plotter (Nolette *et al.*, 1992),
- R-Wel Desktop Mapping System (Welch, 1989), and
- TOPCON PI-1000 (Lammerts, 1991).

Mono DPWS

The mono DPWS are based on digital monoplotting, mainly from orthoimages. Whereas the planimetric information is digitized from the orthoimage, the related height information comes from the DTM which was used for creating the orthoimage. Thus, 3D information can be obtained without having to use stereo imagery. Therefore, the mono DPWS can also be used by operators without a special background in photogrammetry.

The accuracy of the results is only as good as the accuracy of the underlying DTM, and the ability to identify certain features in mono images is more difficult than in stereo. Therefore, the main applications of a mono DPWS lie in areas with less demanding accuracy requirements. Some of the systems include software for image orientation, automatic DTM generation, and orthoimage generation. Examples are

- Galileo Siscam Orthomap (Capani and Muciaccia, 1990);
- I²S PRI²SM (Boniface, 1992);
- Leica Digital Photogrammetric Workstation DPW 610, 650, and 670 by Helava (Miller *et al.*, 1992); and
- Zeiss PHOCUS-PM (Mayr, 1993).

Aerotriangulation DPWS

Aerotriangulation DPWS are used for deriving the parameters of exterior orientation by measuring control and tie point coordinates in multiple images and subsequently performing a bundle adjustment. Point transfer is carried out automatically under the guidance of the human operator, who can see multiple images on the screen, one in each window. At the moment only one such DPWS is available on the market:

- Leica Digital Photogrammetric Workstation DPW 100 by Helava (Miller *et al.*, 1992).

DTM DPWS
As the name implies, DTM DPWS extract a DTM from stereo imagery, in general, in an automatic batch process. Some DTM DPWS include software for image orientation and a DTM program package, some require epipolar resampling as a special step in deriving the DTM, and some are specialized for small-scale imagery and/or for special sensors. There exists a varying degree of verification and editing possibilities, and, thus, different accuracy levels are reached. We found the following systems:

- ERDAS Ortho MAX 1993 (ERDAS, Company Information),
- GeoSpectra ATOM (Geospectra, Company Information, 1989),
- Horler Information HI-VIEW (Horler Information, Company Information, 1992),
- Inpho MATCH-T (Ackermann and Krzystek, 1991)[3],
- Institut für digitale Bildverarbeitung, RSG (Raggam *et al.*, 1991)[4],
- NEC PC-based digital photogrammetric system (Mori *et al.*, 1992),
- PCI EASI/PACE Satellite and Airphoto DEM package (PCI, Company Information, 1992),
- SAIC GIS MAGIC (Poehler *et al.*, 1993)
- Terra-Mar Height Extraction Module (Terra-Mar, Company Information, 1991),
- Trifid DEM correlation software (Trifid, Company Information, 1991)[5], and
- Zeiss TopoSURF (Mayr, 1993)[3].

Orthoimage DPWS
On an orthoimage DPWS, the digital orthoprojection is carried out. Most systems include software for mosaicking and orthoimage map generation, and have interfaces to existing scanners and raster plotters. Existing systems are

- ERDAS Ortho MAX 1993 (ERDAS, Company Information),
- GeoSpectra ATOM (Geospectra, Company Information, 1989),
- HJW OrthoView (Hammon, Jensen, Wallen, Company Information, 1992),
- Horler Information HI-VIEW (Horler Information, Company Information, 1992),
- ISM SysImage - Digital Geo-Coded Imagery System (ISM, Company Information, 1992),
- PCI EASI/PACE Satellite and Airphoto Ortho (PCI, Company Information, 1992),
- SAIC GIS MAGIC (Poehler *et al.*, 1993)
- Signum IS 200 (Gerhard, 1991),
- Trifid orthorectification software (Trifid, Company Information, 1991)[5], and
- Zeiss PHODIS OP (Mayr, 1993).

Use of DPWS in Practice
In this section, an overview of work in digital photogrammetry using DPWS, carried out by and reported on by civil mapping organizations, is given. Recently, private companies have also started to offer services in digital photogrammetry, mainly for scanning photographs and in orthoprojection, but also for DTM generation. However, apart from advertisements, very little information on such services was available at the time of writing. Therefore, discussion of such activities must be postponed to a later date. The work of military organizations, which are known to be involved in digital photogrammetry since its early days (e.g., Case, 1982; Miller *et al.*, 1992) is also not considered in this section, because information on current activities is not generally available, especially in Europe. The experience gained in military applications, however, at least to some extent, has been used in the design of commercial DPWS. Experiments with SPOT imagery are considered only insofar as they are conducted in a production oriented environment using digital data rather than film hardcopies. Other work with SPOT data can be found in Ahokas *et al.* (1990) and Dowman (1991b). Table 1 lists the activities in digital photogrammetry known to the author. When studying this table, the reader has to keep in mind that in different countries mapping has been carried out in different ways in the past. Therefore, it is not surprising that different organizations tackle digital photogrammetry in different ways.

The Institut Cartogràphic de Catalunya (ICC) in Barcelona had started first developments in digital photogrammetry more than 5 years ago. The aim was to produce a large- and medium-scale orthoimage map series for the whole of Catalunya. Because at that time no commercial software for digital orthoprojection was available, it was developed in-house. The resulting system has been in production since 1988. Today, up to 30 orthoimages and a number of orthoimage maps are being produced daily. Recently, the 1:5.000- and 1: 25.000-scale orthoimage map series were completed for the whole of Catalunya (Colomina, personal communication, 1993). Also, work in stereo plotting was started in the development department.

In Great Britain, orthophotos have always been less popular than in most other countries. It is, therefore, not surprising that the Ordnance Survey (OS) has put more emphasis on other tasks. In aerotriangulation, significant time savings were achieved for point transfer and the accuracies reached were only a bit lower than those obtained with analytical photogrammetry. Automatic DTM generation was successful for images of good photographic quality and texture, while problems occurred in more difficult terrain.

The Landesvermessungsamt Nordrhein-Westfalen (LVA NRW) is about to produce an orthoimage map series at a scale of 1:5.000. Production of 1800 map sheets per year will start shortly. The orthoimages are also planned to be used for GIS updating. Furthermore, research in automatic extraction of control points for computing the exterior orientation parameters has been reported recently. This work is being carried out at Bonn University in cooperation with the LVA NRW. The results are promising, and the algorithms will be implemented at the mapping organization in the near future.

The U. S. Geological Survey (USGS) has carried out a large mono plotting test from orthoimages for the revision of the 1:24,000-scale base map of the United States. The result is that mono plotting alone is not accurate enough for this goal, mainly due to problems in feature identification. Research is also being carried out in automatic DTM generation and stereo plotting.

The Canada Centre for Mapping (CCM) is in the state of designing a Topographic Data Base Revision System (TDBRS) for 1:50,000-scale map data around a stereo DPWS, including automatic DTM generation. At the time of writing, however, no information was available on any tests or results.

In the Survey Department of the Netherlands, experi-

[3]MATCH-T is also available as part of the Intergraph ImageStation and - under the name TopoSURF - from Zeiss.
[4]Also distributed by GEOSPACE.
[5]Only available as part of the Intergraph ImageStation.

TABLE 1. CIVIL MAPPING ORGANIZATIONS USING DPWS

Organization	Task	Hard- and Software	Source
ICC, Spain	orthoprojection, orthoimage map generation	in-house development on general purpose workstation	Arbiol *et al.*, 1987; Colomina *et al.*, 1991
	stereo plotting	Intergraph ImageStation	Colomer, 1993
OS Great Britain	aerotriangulation	Leica/Helava DPW 100	Newby, 1990, 1991; Farrow, Murray, 1992
	DTM generation	Leica/Helava DPW 710, 750	
LVA NRW, Germany	orthoprojection, orthoimage map generation	Signum IS 200	Düren, 1992
	determination of absolute orientation parameters	in-house development on general purpose workstation	Schickler, 1992
USGS, United States	monoplotting stereo plotting	Intergraph SAIC	Skalet *et al.*, 1992 Poehler *et al.*, 1993
CCM, Canada	stereo plotting	MacDonald Dettwiler	Ahac *et al.*, 1992
Survey Department, The Netherlands	aerotriangulation	Leica/Helava DPW 100	Han, 1992
GSI, Japan	map generation from SPOT	in-house development on general purpose workstation	Akiyama, 1992
IGN, France	stereo plotting	Matra MS2I Traster T10	Jamet, private communication, 1992

ments were conducted for automatic point transfer in aerotriangulation. Accuracies between 5 μm and 7 μm for tie points, and time savings of a factor of 3 to 5 were convincing enough to introduce the system into production in early 1992.

The Geographical Survey Institute (GSI) of Japan has reported mapping activities from SPOT imagery for 1:100,000-scale applications. The experiments were not conducted to suit domestic needs but to suit those of developing countries. The first successful projects were carried out in cooperation with Peru.

Finally, the Institut National Géographique (IGN) de France recently started a research program for using stereo DPWS for map revision. Again, reports on test results are not yet available.

In summary, digital orthoprojection, not surprisingly, has had the most success so far. It seems that automatic point transfer for aerotriangulation and interactive stereoplotting will follow shortly, while automatic DTM generation in practice still has a long way to go. It remains to be seen whether the results for mono plotting obtained in the United States are also valid for other countries.

Conclusions

What are the main requirements of the users? Newby (1991) stated that, compared to analytical photogrammetry, digital photogrammetry and DPS must prove clear economic benefits. The accuracy and the overall quality of existing products must be at least the same, and the product costs must decrease. Additionally, new products are desirable. Time savings must be possible to allow for faster map revision cycles, which are badly needed in most countries. The integration of old techniques into the new workflow must be guaranteed, and not only photogrammetry but also cartography must be carried out in the digital domain. Even though it can be seen as an advantage to integrate all tasks of the photogrammetric processing chain into one system, a modular approach must be adopted, especially for large mapping organizations, because the different tasks of the photogrammetric processing chain are and will remain to be carried out by different people in different places. Nevertheless, DPS must be capable of doing the whole job, not just parts of it. This means that end-to-end systems including scanners, raster plotters, and GIS interfaces must be provided. Last but not least, the DPS must be equipped with a comfortable user interface.

What are the main trends in digital photogrammetry and in DPS development? Will the requirements of the practitioners be fulfilled? Photogrammetric equipment manufacturers will increasingly become companies of system integration and software development rather than manufacturers of special photogrammetric hardware (perhaps with the exception of aerial cameras and hardcopy scanners). Sooner or later it will be possible to build a DPS with only commercial off-the-shelf parts. This has already been proven for DTM DPWS and orthoimage DPWS. Image compression algorithms will be introduced into DPS in order to reduce the huge amount of data. Efficient and user-friendly software, especially that running on different hardware platforms, will be the key factor to success. Therefore, standards will emerge for hardware and software as well as for data exchange. Developments outside photogrammetry (digital image acquisition, parallel computing, neural networks, modern user interfaces with speech recognition, head mounted devices, and the like) will also have their effects on digital photogrammetry.

Orthoimages, the commercially most successful product of digital photogrammetry today, are increasingly becoming an additional layer of a hybrid GIS. Besides serving as pictural background information, they are also used for GIS updating (despite the results obtained at the USGS). For topographic applications, DPS are more and more considered as systems for GIS data acquisition and revision. Automatic DTM generation is operational, at least from small-scale imagery. At larger scales, semi-automatic approaches have given promising results. Work is also under way in universities and companies to automate additional tasks such as interior and relative orientation. Semi-automatic approaches for feature extraction will take some time before being implemented in a DPS. Although impressive research results have been obtained in image understanding, a complete automation of the photogrammetric processing chain seems out of reach today.

Taking all these trends and developments into account, DPWS are on the verge of replacing the analytical plotter and digital photogrammetry seems well and healthy on its way into practice.

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