Overview of European Developments in Digital Photogrammetric Workstations

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ABSTRACT: The current position of European Softcopy or Digital Photogrammetric Workstations (DPWS) in terms of operational systems as well as research and development activities is reviewed. European manufacturers (Leica, Matra, Galileo Siscam) have made significant strides in developing universal type DPWS for topographic applications. Operational close-range DPWS include the MAP VISION system and the Rolleimetric RS product line. European mapping organizations such as the Ordnance Survey (United Kingdom), the Institut Géographique National (France), the Institut Cartogràfic de Catalunya (Spain), the Landesvermessungsamt Nordrhein-Westfalen (Germany), and Eurosense (Belgium) have made first steps in using DPWS in the production environment, mainly for the automatic computation of digital terrain models and for orthoprojection.

Within the universities there has been considerable research activity concerning design issues of DPWS, often focusing on specific applications. For example, work is in progress in Berlin, Glasgow, Hannover, and London on topographic applications, in Braunschweig and Zürich on close-range applications, and in Graz, London and Oberpfaffenhofen on radargrammetry. Similarly, a body of work on algorithmic aspects of DPWS has been carried out in Bonn, Darmstadt, Delft, Enschede, Karlsruhe, Lausanne, Munich, Stockholm, Stuttgart, and Zürich.

These activities are reviewed and lead to a number of conclusions on the state-of-the-art and on future trends. The major ones are

- A DPWS is and will remain an interactive workstation, where the human operator handles less and less routine work, but stays responsible for verification and control.
- Digital orthoprojection is on the verge of becoming widely used in practice. Image matching techniques are applied in a number of DPWS for small-scale applications. The use of operational image understanding methods in DPWS has not yet been achieved.
- The incorporation of data from different sources, for example, optical and microwave imagery, is increasingly being recognized, as is the connection between DPWS and GIS.

INTRODUCTION

DURING THE LAST DECADE there has been an increasing interest in the use of digital image data, which has led to the development of photogrammetric systems to process those data. These developments date back to the early 1980s (Sarjakoski, 1981; Case, 1982; Albertz and König, 1984). There was a buildup to the XVIth Congress of the International Society for Photogrammetry and Remote Sensing (ISPRS) in Kyoto 1988, where two systems by commercial vendors were on display and others were discussed in technical sessions. Since 1988 the field has grown rapidly.

These systems have come to be known as Softcopy or Digital Photogrammetric Workstations (DPWS). A DPWS consists of hardware and software to carry out photogrammetric tasks in an interactive and automated way using digital image data as input. The resulting photogrammetric products include three-dimensional (3D) coordinates, geometric and radiometric object surface descriptions, structured vector data, transformed digital imagery (for example, orthoimages and perspective views), and combinations thereof (Grün, 1989; Dowman, 1990).

Many factors have influenced the developments of DPWS, including the drive for automation due to high labor cost, the need for real time operations in quality control and robotics, the availability of digital imagery from satellites, the development of accurate and affordable digitizers and CCD cameras, the inherent stability of a purely digital system, and the availability of low-cost computer components to provide the required speed, storage, and display facilities.

Another important factor has become more recognized recently: the need for integration of information from different sources. The development of Geographic and Land Information Systems (GIS/LIS) and Computer Aided Design (CAD) systems for handling spatial data provides this information to many different users. GIS/LIS and CAD progress has largely contributed to the development of DPWS, which act as the data acquisition component, provide an active window into the database, and give access to a large toolbox of photogrammetric, data management, and visualization techniques.

This paper reviews the developments of European DPWS. It contains four main parts. In the first part operational systems, which are already available on the market, are discussed. These are subdivided into systems designed mainly for topographic mapping and special systems in a close-range environment. The second part of the paper reflects the use of DPWS for topographic applications. Examples are given from government organizations as well as from private companies. Ongoing research activities concerning the design of DPWS are discussed in the third part. Again, a distinction is made between research for topographic and close-range applications. The final part focuses on research into algorithmic aspects of DPWS.

The discussion of data structures for GIS/LIS and CAD, and the development of systems for integrated acquisition of geodetic and photogrammetric data such as video theodolites, are beyond the scope of this paper. Also hybrid systems, for example, analytical plotters equipped with CCD cameras, are not discussed in the following.

SOURCES

At the XVIth ISPRS Congress in Kyoto in 1988 the Intercommission Working Group II/III (IC WG II/III), "Design and Algorithmic Aspects of Digital Photogrammetric Systems," was established. The authors serve as chairmen (chair: H.Ebner; co-

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chair: I. Dowman) and secretary (C. Heipke) of the working group. IC WG II/III reports to Commission II, "Systems for Data Processing and Analysis," and to Commission III, "Mathematical Analysis of Data."

One of the main sources of information about developments relating to DPWS is the joint workshop of IC WG II/III and WG V/3 entitled "Hardware and Software for Fast Image Data Processing," which was held at University College London (UCL) in February 1990. A number of conclusions were reached at that meeting:

- Special purpose hardware systems are being developed but these are not yet used in DPWS which tend to use commercial-off-the-shelf products;
- there is an increasing use of transputers and transputer based systems but there is also argument as to whether workstations using RISC architecture may be more efficient;
- image matching algorithms have been successfully applied to satellite and small scale images but more work is needed in order to apply them to large scale mapping; and
- further research and development is necessary in the extraction of image features (points, lines, areas), in image understanding, and for the efficient parallelization of algorithms.

IC WG II/III also held sessions at the ISPRS symposia of Commission III in Wuhan (May 1990) and of Commission II in Dresden (September 1990) which contained papers on new developments on all aspects of DPWS. Further aspects were covered at the ISPRS symposia of Commission IV in Tsukuba (May 1990) and of Commission V in Zürich (September 1990). An IC WG II/III report is contained in Ebner *et al.* (1990).

Two papers presented at the ISPRS Commission Symposia deserve special mention from a European perspective as they indicate the theoretical advances being made. Sarjakoski (1990) sets out the potential for digital stereo imagery and discusses requirements for DPWS and Förstner (1990) reviews the concepts and algorithms for digital photogrammetric systems.

In addition to the ISPRS proceedings, this review is based on the regular periodicals of photogrammetry and remote sensing and on related publications.

OPERATIONAL SYSTEMS

Five European systems can be classified as operational: the Kern DSP1 (Cogan *et al.*, 1988) and the Matra TRASTER T10 (Cruette, 1990), both universal type systems; the Galileo Siscam ORTHOMAP system (Capanni and Muciaccia, 1990); the MAP VISION system (Haggrén, 1986); and the Rolleimetric system (Rollei, 1986). It must be said, however, that it is not always easy to distinguish between operational and research systems. It is assumed that, if a system is advertised for sale, then it is operational.

One of the first universal type operational DPWS, the CONTEXT VISION system (Lohmann *et al.*, 1989), is not included in this review. Although its concept and realization were a major breakthrough, it is unfortunately not available on the market any more.

The Kern DSP1, now manufactured by Leica, Aarau, was first presented at the ISPRS Congress at Kyoto in 1988. The architecture of the DSP1 is very similar to that of the Kern DSR range of analytical plotters (Chapuis and van den Berg, 1988). The P2 processor, which moves the stage plates in the real-time measuring loop on the DSR instruments, holds the digital images and controls the digital display hardware. Transputer boards, developed by GEMS of Cambridge Ltd. (now part of Ramtek Ltd.), are available for high speed processing. The software for analytical photogrammetry is almost exactly the same as used in the DSRs and runs on a VAX under VMS. The DSP1 uses a split screen display on a high resolution monitor with 1280 by 1024 pixels and optics which incorporate image rotation and zooming. Other features of the system include image enhancement, superimposition of vector information, image matching and digital elevation model (DEM) computation, and the generation of perspective views.

The TRASTER T10 Softcopy Stereo Workstation from Matra SEP Imagerie et Informatique (MS2i) is also a universal type instrument. It was developed from the Matra analytical plotters in the course of the French SPOT satellite program, but it can also process digital aerial imagery. The TRASTER T10 was announced in Kyoto (Euget and Vigneron, 1988), but was not exhibited until November 1990. It takes into account the developments which have taken place since 1988 such as the production of faster workstations and the increasing recognition of the importance of GIS. The system includes a SUN-SPARC station running under UNIX and a special processor to handle the real-time measuring loop. Dedicated array processors are used for image rectification, matching, resampling, and general image processing tasks. The stereo display is based on polarization on a high resolution color monitor.

Galileo Siscam has presented the ORTHOMAP system for digital orthoimage generation and map compilation at the ISPRS Commission V Symposium in Zürich in 1990. It includes a scanner interface to convert hardcopy images into digital format, an Intel 80386 based personal computer under UNIX, a high resolution monitor, and an interface to various hardcopy output devices. The software allows for measurement of control points, space resection, and orthorectification using an existing DEM. Subsequently, map compilation can be performed from the orthoimage. Stereo viewing and measurements are not supported.

The requirements of close-range DPWS tend to be different from those for topographic mapping. Usually, only a reduced amount of data has to be processed, but speed is more important. In robotics real time demands have to be fulfilled. Thus, automation and speed are the main objectives, while stereo display and fast scrolling over large image areas are less important.

The MAP VISION system developed at the Technical Research Center of Finland, was presented in 1986 (Haggrén, 1986), although first developments date back to 1984 (Haggrén, 1984). It was especially developed for industrial quality control applications and produces 3D point coordinates. MAP VISION consists of up to four standard CCD cameras and commercial off-the-shelf processing hardware. The key factor to a relative accuracy of about 1:5000 is the in-house-built external synchronization of each camera. The exterior orientation parameters are calculated prior to the actual point measurements in a calibration procedure. Points to be measured have to be signalized with a laser beam or special reflective targets. The processing time is around one second per point.

A modular approach to DPWS was taken by Rollei. One might hesitate to find this offering in a list of operational DPWS systems. But the components of the Rolleimetric RS product line and the new Rollei RSC (Réseau Scanning Camera; Riechmann, 1990) meet the requirements of a DPWS for off-line close-range applications. Scientific support for Rollei comes mainly from the Technical University Braunschweig. Common features of all components include the use of réseaus for accuracy improvement (Wester-Ebbinghaus, 1989). Digital imagery is acquired by the RSC, a 6 by 6 camera in which a standard CCD sensor is moved in the image plane to successively scan the whole image. Further processing includes automatic measurement of image coordinates of signalized points, and the computation of 3D coordinates.

USE OF DPWS FOR TOPOGRAPHIC APPLICATIONS

This section describes the use of DPWS in topographic mapping. First, the work of government mapping agencies is reported. These organizations recognize the importance of techniques using digital imagery but are slow in introducing such techniques. We also discuss activities of private companies and other organizations which offer services in digital map production and partly also sell their software to clients. Their main areas of interest are the computation of a DEM and the production of orthoimages.

The Ordnance Survey (OS) in the United Kingdom has recognized that digital data have a place in mapping. SPOT data have been used for map production at a scale of 1:100 000. Investigations are under way for mapping at 1:50 000 scale, for automatic DEM generation, and for orthoimage production. However, the demand for these products comes from outside the United Kingdom and this type of work does not comprise a significant part of OS production. OS has purchased a Helava Associates Inc. (HAI) Digital Comparator Correlator System (DCCS) for aerial triangulation (Newby, 1990). The system has produced acceptable results in less time than those obtained by the current method of aerial triangulation using a DSR1 which meet the requirements of OS for normal production work. OS is also looking at the HAI-500 DEM and orthoimage generator.

The Institut Géographique National of France (IGN) is also interested in the use of digital data. IGN have made more use of SPOT data for mapping than OS. They have also used image matching techniques for DEM generation for a number of years (Guichard *et al.*, 1987), but have not reported the use of DPWS for map compilation.

Work at the Institut Cartogràfic de Catalunya (ICC) in Spain has also been concentrated on orthoprojection (Arbiol *et al.*, 1987). Orthoimage maps at the scale of 1:5000 are being produced at a throughput of one map every 2 hours. The bottleneck to a faster production is the interactive text placement in the derived orthoimage. Hardware at the ICC includes a Joyce Loebl Scanner, a DEC Vaxstation 3100, an Intergraph IP 225, and an Optronics plotter (L. Colomer, personal communication, 1991).

In Germany, the Landesvermessungsamt Nordrhein-Westfalen is the government organization most advanced in topographic mapping using digital data. A concept for operational orthoimage production was established in 1989. The implementation of this concept is carried out by the company SIGNUM GmbH, Munich (Gerhard *et al.*, 1990). Production of eight orthoimages daily (100 MB each) is to start in early 1992.

The main private European company involved into DPWS is Eurosense Belfotop NV, Belgium (Eurosense, 1988). They operate a digital color orthoimage system called EUDICORT (Eurosense Digital Cartographic Orthophoto System). Aerial photographs are scanned and rectified on an I²S image processing system. Mosaicking software allows for computing a high quality orthoimage from more than one input image.

ISTAR of France offer DEM and orthoimages produced automatically from digitized small scale aerial photographs or SPOT data and can also generate perspective views (ISTAR, 1989). The software package GEODEM of UCL also offers DEM and orthoimages as well as visualizations of the terrain (UCL, 1990). The emphasis in both systems is on the algorithms for automatic image matching, but interaction of the operator is necessary for selection of ground control points, validation, and for manual completion of areas which could not be matched automatically. The Industrieanlagen-Betriebsgesellschaft (IABG), Munich, has developed the software package DIR (Digital Image Rectification) for the generation and mosaicking of color orthoimages in cooperation with the Technical University Munich (Mayr and Heipke, 1988). The services offered also include automatic DEM generation from SPOT imagery (Heipke, 1990).

RESEARCH INTO DESIGN ASPECTS OF DPWS

This section deals with European research activities for the design of DPWS. Again, a distinction is made between systems for topographic mapping and for close-range applications.

At UCL, a first system for mapping from stereo SPOT data using an I²S image processing system was realized (Gugan and Dowman, 1986). Software for automatic DEM generation (Otto and Chau, 1989; Day and Muller, 1989) and for stereo image display and point measurement using split screen viewing (Muller, 1988) has been developed for SUN workstations. A Parsys Supernode system of transputers has been added in order to accelerate the DEM generation. In a parallel development, a stereo photogrammetric workstation is being implemented at UCL which will allow feature extraction and data integration (Dowman and Upton, 1991). Different data sources will include satellite images, synthetic aperture radar (SAR) images, DEM, and GIS information. The system is based on a SUN-SPARC station and will probably make use of the new SUN-VX image accelerator.

A workstation for SAR data has also been developed at the German Aerospace Research Establishment (DLR), Oberpfaffenhofen in cooperation with the Institute for Image Processing and Computer Graphics, Graz (Schreier, 1989; Buchroithner, 1990). The objective of such a workstation is to allow rapid access to the DEM and map data required for geocoding of SAR imagery, to select ground control points, to allow visualization of geocoded imagery, and to carry out quality control. The system is based on SUN workstations using SUN-TAAC boards for greater image processing power. The display tool is based on the monoscopic display developed at UCL which has been modified and enhanced for the requirements of DLR.

At the Technical University of Berlin, a first concept of a DPWS was published in 1984 (Albertz and König, 1984). Two years later the experimental Digital Stereophotogrammetric System (DSS) based on a VAX 11/750 was described (König *et al.*, 1986). Recently, work on the advanced DSS which runs on a SUN-SPARC station under UNIX and is extended with a PARACOM Multicluster of 14 transputers has been reported (König *et al.*, 1990). The system is intended for topographic mapping, DEM computation, and orthoimage and orthomap generation.

In the course of the second German spacelab mission D2, the three-line camera MOMS-02 will acquire digital imagery from space (Ackermann *et al.*, 1989). The launch is planned for 1992. In this context, a DPWS is being developed in a joint effort of the photogrammetric departments of the universities in Bonn, Hannover, Munich (Technical University and University of Armed Forces), and Stuttgart. The DPWS will allow for fully digital processing of three-line imagery including, the reconstruction of the exterior orientation, DEM and orthoimage generation, and mapping applications (Lohmann *et al.*, 1990; Ebner and Kornus, 1991; Hahn and Schneider, 1991; Siebe *et al.*, 1991). It will be based on a SUN-SPARC station under UNIX. The SUN-VX accelerator will be used for image manipulation and display. Stereo viewing is made possible using active glasses, which are synchronized to the refresh frequency of the screen. The left and right images are shown alternatively for 1/120 sec each, allowing for flickerfree display.

At the University of Glasgow in the United Kingdom, a system for mapping from digitized aerial photographs has been developed on an IBM 5080 workstation linked to an IBM 3090 mainframe, incorporating automatic techniques for the reconstruction of the interior orientation and image matching in epipolar lines (G. Petrie, personal communication, 1991).

Research on close-range DPWS in Europe is best illustrated by work at ETH Zürich (Grün, 1989; Grün and Beyer, 1990). A modular approach has been taken to build the Digital Photogrammetric Station II (DIPS II). It consists of commercial off-the-shelf hardware components, based on a number of SUN workstations and includes CCD cameras for data acquisition. DIPS II mainly serves research interests in algorithms. Thus, there is no need for intensive operator driven measurements and the stereo display capabilities need not be very advanced. Emphasis lies on the integration of software for various tasks. An easy-to-use window interface called DEDIP (Development Environment for Digital Photogrammetry) has been implemented, which includes possibilities for camera orientation, automatic point measurement, image matching, on-line bundle adjustment, and others.

RESEARCH INTO ALGORITHMIC ASPECTS OF DPWS

This section of the paper reviews procedures which will be incorporated into DPWS in the future. Research into algorithms for DPWS can be classified into two main groups: algorithms for geometric results (point coordinates, DEM, orthoimages) and algorithms for semantic results (object or scene descriptions, for example, maps; see also Förstner (1990)). The first group has been a research topic since at least the late 1970s, when first concepts for automatic DEM computation and digital orthoprojection where published (Kreiling, 1976). The latter group includes image understanding and is only recently being tackled by the European photogrammetric community. A comprehensive comparison between digital and analytical techniques and systems is given by Makarovic (1990).

Digital orthoprojection has in the meantime advanced into practice. Research topics include modeling and consideration of terrain features not included in the DEM (for example, buildings and forests) and the detection of areas not visible in the input image (Behr, 1989), special algorithms to speed up the computing time, and mosaicking of large areas (Mayr, 1990), as well as software engineering and user interface design (Baltsavias *et al.*, 1991).

Image matching has reached a first somewhat stable state. DEM generation from small-scale aerial images and from SPOT stereo pairs is feasible in an automatic way. Also, object surfaces can be derived automatically in a controlled laboratory environment (Claus, 1986). Results of a comprehensive test on image matching involving 18 research institutes from all over the world are reported by Gülch (1988). Excellent surveys on image matching are reported by Lemmens (1988) and Wrobel (1988). In general, image matching is still an unsolved problem, but significant progress has been made. Least-squares image matching (Förstner, 1982; 1984) has been found to be most accurate (Hahn and Förstner, 1988). It has been extended in a number of ways (Grün, 1985; Rosenholm, 1986; Ebner *et al.*, 1987; Wrobel, 1987; Helava, 1988; Otto and Chau, 1989).

Recently, global approaches which perform matching in object space have been studied intensively (Wrobel, 1989; Heipke, 1989). The model allows for a unified approach to image matching, point determination, surface reconstruction, and orthoimage generation and includes reflectance properties of the object surface. Image pyramids and scale space algorithms (Burt and Adelson, 1983; Witkin, 1983) are increasingly being used to achieve good starting values for image matching and to speed up the computations (for example, Baltsavias, 1988; Hahn, 1989; Li, 1989; Hahn, 1990; Heipke, 1991). Other developments include the consideration of breaklines for DEM generation (Kölbl and da Silva, 1988; Li, 1989; Kölbl *et al.*, 1991). Feature based matching has not been very popular in photogrammetry, but successful applications are reported, for example, by Förstner (1986) and Hahn (1989). Relational matching is a focus of studies (Vosselman, 1989) but will have to be further developed for practical applications. A review of techniques for deriving object shape from digital imagery (shape from X) is contained in Weisensee (1990).

As for image understanding, first results have been achieved in recent years. Research is concentrated on large scale imagery. A test on image segmentation and raster-to-vector conversion has been issued by the European Photogrammetric Organisation (OEEPE) under the leadership of Delft University. Another example is the work by Sester and Förstner (1989), who automatically detected house roofs and use them as control information for the estimation of the exterior orientation of image pairs.

Knowledge-based procedures are employed for the description of objects and their extraction from large-scale imagery in an ambitious project in Stockholm (Gülch, 1989; Gülch *et al.*, 1990). The usefulness of hierarchical approaches for the description of images and also of knowledge about the depicted scene are described by Sester (1990).

In general, image understanding is becoming a hot research topic in Europe. It is being recognized that heuristic methods must be replaced by procedures which also yield accuracy and reliability, especially if only little human control can be tolerated. Also, more complex models involving at least the physics of image creation and the modeling of objects in the scene are absolutely necessary. In a DPWS the algorithms studied will be available in interactive procedures sooner or later. However, we have no indications that a map will be derived entirely automatically from digital imagery in the near future.

CONCLUSIONS

This paper presents recent developments and the state-of-the-art of DPWS in Europe. Furthermore, trends in research activities have been outlined. We arrive at the following major conclusions:

- A DPWS is and will remain an interactive workstation, where the human operator handles less and less routine work, but stays responsible for verification and control.
- Therefore, the human interface is essential for a DPWS. It will be one of the most decisive factors for a wide use of DPWS in practice.
- Special hardware is being used in today's operational systems (especially transputers), but a tendency can be observed to employ commercial off-the-shelf products in a modular approach.
- Standard computer architectures, especially RISC architectures, are becoming more and more popular.
- The civilian European market seems not ready for the highly priced universal type systems yet.
- The number of companies involved in the realization of DPWS is becoming larger. Besides the traditional photogrammetric companies, electronic and computer science firms are increasingly bringing products on the market.
- Digital orthoprojection is on the verge of becoming widely used in practice. Image matching techniques are applied in a number of DPWS for small-scale applications. The use of operational image understanding methods in DPWS has not yet been achieved.
- The incorporation of data from different sources, for example, optical and microwave imagery, is increasingly being recognized, as is the connection between DPWS and GIS.

In summary, it can be said that significant progress has been achieved in the field of DPWS in Europe, but the benefits of such systems still have to be demonstrated more clearly. A comment from the Ordnance Survey is worth quoting: "There are legitimate doubts about the ability of digital photogrammetry to compete successfully in the civilian market, but we should remember that only about 12 years ago, exactly the same thing was being said about the analytical plotter" (Newby, 1990).

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