Digital Photogrammetric Workstations - A review of the state-of-the-art for topographic applications

Abstract
Since its first appearance in the commercial world during the ISPRS Congress in Kyoto in 1988 digital photogrammetric workstations (DPWS), sometimes also called softcopy workstations, have come a long way. For some, DPWS were thought of as a substitute of analytical plotters using mostly manual measurement techniques, others argued that the human operator would soon be replaced by totally autonomous processes, being performed at extremely high speed. Yet others foresaw cheaper and more flexible systems being easier to use and yielding a variety of new high quality products. Various commercial systems started to be available on the market, albeit some of them disappeared soon afterwards. The stormy first phase of development seems to be over, as we see less announcements for new systems and more mature products. This article attempts to summarise the current state-of-the-art of DPWS for topographic applications and to discuss some trends for future developments.

Introduction
In the late 80´ies the International Society for Photogrammetry and Remote Sensing (ISPRS) had defined a DPWS as "hardware and software to derive photogrammetric products from digital imagery". While this definition still holds today, already in 1990 Ian Dowman from University College London added, that a DPWS was also an active window into the data base of a geographic information system (GIS), clearly pointing towards the increasingly important integration of photogrammetry (and thus DPWS) and spatial information science (and thus GIS). Today, DPWS are well established in the market place and are in fact taking over from analytical plotters as the main work horse in photogrammetry, at least in the number of sales (see figures 1 and 2 for two examples). However, as was to be expected, only some of the promises came true, while other hopes have turned out to be far too optimistic.

Components of a DPWS
On the hardware side a DPWS is composed of standard components including stereo viewing devices and a three-dimensional mouse. While Unix machines were still strong a few years ago, today, virtually every DPWS is based on a PC equipped with a Windows operating system. The core of a DPWS is of course the implemented software which can be subdivided into different levels. The operating system was already mentioned, in addition one can distinguish a data base level for vector, raster and attribute data, a level for image handling, compression, processing and display, and a level of photogrammetric applications such as image orientation, the generation of digital terrain models (DTM) or the capture of structured vector data, and the user interface level.

Automation
Since the beginning, automation was seen as one of the main advantages of DPWS as compared to an analytical plotter. Following the definition suggested by Gülch automation is subdivided into (a) semi-automatic modules in which a human operator is constantly in control of the process and is being supported by automatic procedures running in real time, (b) automated modules for which the operator needs to define input parameters prior to running the process, and must carry out quality control at the end of the process, and (c) autonomous modules which run completely independent of any human intervention.
Major research and development efforts were spent on image matching techniques in order to automatically generate DTMs, extract tie points for relative orientation and bundle adjustment, and to generate orthophotos and orthophoto mosaics. It was found that in general, image matching works well in open and not too mountainous terrain. However, problems can for instance occur in larger scale imagery, especially in forests, settlements, water areas, and in regions with poor texture. Also the automatic delineation of a seamline for orthophoto mosaicing still poses some challenges. All mentioned processes can be classified as automated according to the definition given above, since they are controlled by a list of parameters which need to be predefined by a human operator. Also, self diagnosis is missing in most approaches and therefore, each step must be followed by interactive quality control including editing where necessary. Note that setting the parameters correctly prior to the automated process and also the interactive quality control at the end requires a certain level of experience which should not be underestimated. As for vector data capture, remarkable progress could be observed in the research arena over the last decade, mainly focussing on model-based object extraction. Nevertheless, with very few exceptions this task is still being performed manually in DPWS, and at present the only advantage with respect to an analytical plotter is stereo superimposition of the vector data in colour.
Performance tests of the individual tasks involving image matching were carried out, partly by international organisations such as ISPRS or OEEPE, and partly by individual institutions. There is still some discussion about the geometric accuracy achievable within DPWS today, but it seems fair to say that for most applications there is no

difference between DPWS results and those obtained from analytical plotters, if proper interactive quality control is performed. Also, the productivity has significantly increased in many cases.

Integration with geographic information systems

A tendency can be observed to consider a DPWS as a front end data acquisition and updating system for spatial information stored in a GIS. An obvious advantage of combining DPWS and GIS is the easy superimposition of vector and raster data (see e.g. figure 3). Recently, systems have appeared on the market which have a direct link between photogrammetry and GIS. Examples include the combination of Z/I´s ImageStation with Intergraph´s GeoMedia and the connection between Erdas Imagine and ArcInfo from ESRI. The full potential of the integration, however, can only be exploited by a tight coupling such as the one between LH System´s Socet Set and the object-oriented GIS LAMPS2 from Laser-Scan. The main advantage of this tight integration is that geometrical, topological and semantic consistency can be achieved by combining data capture and real time GIS analysis. In this way separate data structuring and validation steps can be avoided, and data quality is significantly increased. Figure 4 depicts a conceptual design of such a tight integration between DPWS and GIS. In this scenario image orientation is a pre-processing step which is performed by a photogrammetric expert, whereas depending on the type of data to be acquired the actual data capture can be carried out by an applications specialist. Another advantage of integrating DPWS and GIS which has been demonstrated at ample occasions in the research field is that vector information from the GIS data base can significantly help semi-automatic and automated vector data acquisition.

Types of commercial systems

In the commercial market we can distinguish a number of different types of systems. They mainly differ in functionality, degree of automation and price. In the first group we can identify multi-purpose systems offered by the traditional providers (Autometric, LH Systems, Z/I Imaging) and also by some newcomers (Erdas, inpho and partners, Supresoft). Using these systems the traditional photogrammetric tasks - image orientation, DTM collection, generation of orthophotos and orthophoto mosaics, vector data capture - can all be performed, in addition various visualisation tools such as fly throughs are available on some systems. Apart from the identification and measurement of ground control points and vector data capture which is usually carried out in a CAD environment, all tasks are highly automated. Stereo viewing is offered in all these systems, and some of them have threaded code and can thus truly take advantage of multiple processors. A second group is formed by systems with somewhat less automation available from smaller companies. While these companies offer the full range of photogrammetric products, the emphasise is mostly on some parts of the processing chain only. Again, some companies have been in the market for a number of years (DVP Geomatis, ISM, KLT Associates, R-Wel), others are relatively new to the field (3D Mapper, Espa Systems, TopoL Software/Atlas, Racurs). In a third group we find the remote sensing systems such as those from ER Mapper, Matra, MircoImages, PCI Geomatics, and Research Systems which serve mainly for the generation of orthophotos, mostly without stereo viewing capabilities. Finally a small number of systems dedicated to automatic vector data capture should be mentioned. Examples include CyberCity Modeler developed at ETH Zurich, eCognition from definions and inJect from inpho. More details about the commercial systems can be found in the product overview contained in this issue.

Improvements and future trends

A few improvements to increase the performance of DPWS can be clearly cited, and in fact have partly been realised already, at least in an experimental stage. These improvements include refinements in image matching, e. g. the use of multiple instead of only two images for DTM generation. Especially if imagery is flown at a high overlap this development should be combined with the generation of true orthophotos in which buildings are properly placed, and walls etc. are not visible in the orthophoto. Another issue which needs to be addressed across virtually all available systems is the lack of substantial self diagnosis within the automatic modules. From the user perspective, intuitive handling of the complete system is another critical point. It should be noted that the interest and the pre-knowledge of the user may greatly differ, especially in a scenario where the DPWS is tightly integrated with a GIS. Therefore, different user groups should be identified, described and given their own user interface in order to be able to make optimal use of the system.

Besides these improvements, general trends in photogrammetry, remote sensing and beyond have, of course, consequences also on the development of DPWS. The integration of DPWS and GIS was already mentioned. In addition the development of the world wide web has a major impact, because the WWW presumes digital images in the first place and is certainly one of the main reasons for the fact that film based imagery is more and more often scanned immediately after acquisition, and subsequent processing is then naturally performed using a DPWS. Other trends are the direct determination of image orientation by GPS/INS and DTM generation by laser scanning (lidar) or interferometric radar. These developments have changed the significance of aerial triangulation and automated DTM

generation by image matching and have contributed to shifting the attention more towards vector data collection and GIS integration.
At present the community is also eagerly awaiting the first images of the commercial digital airborne cameras. Together with the recent advent of high resolution satellite imagery the consequence for DPWS will be twofold: (1) Besides central perspective projection alternative geometric sensor models will become more important and may trigger new developments in multi-sensor geometry. This development may also lead to the use of sensor-independent approximations of the collinearity equations such as rational polynomials which have been in use for years in some remote sensing applications. Research is needed to clarify, to which extent they can also be used in standard aerial photogrammetry. (2) We will see an increasing integration of panchromatic and multi-spectral images, especially in automated processes. At present, however, it is not clear which combination of spectral band should be used for which object class, and how a successful strategy for automated vector data extraction integrating multi-spectral classification and model-based object extraction should look like.

Further contacts
ISPRS has formed an Intercommission Working Group II/IV entitled "Systems for automated geo-spatial data production and update from imagery". Some of the topics treated in the working group are relevant to DPWS, e. g. the evaluation and implementation of semi-automatic systems for object capture and update and the GIS-driven change detection, spatial data capture and revision. For more details see http://www.commission2.isprs.org/icwg2_4.

Suggestions for further reading
Edwards D., Simpson J., Woodsford P. (2000): Integration of photogrammetric and spatial information systems, IAPRS, Vol. XXXIII, Part B2, pp. 603-609.
Gülch E. (2000):Digital systems for automated cartographic feature extraction, IAPRS Vol. XXXIII, Part B2, pp. 241-256.
Grün A. (1999): Digital Photogrammetric Stations, GeoInformatics, Vol. 2, pp. 22-27.
Kölbl O., Ed. (1999): OEEPE-Workshop on Automation in Digital Photogrammetric Production, OEEPE Official Publication No. 37, ISSN 0257-0505.
Petrie G. & Walker S. (2000): Digital photogrammetric systems approach maturity, GeoInformatics, Vol. 3, pp. 18-25.

Bibliography of the author
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Figure 1: Z/I ImageStation (Copyright Z/I Imaging)

Figure 2: LH System Digital Photogrammetric Workstation (Copyright LH Systems)

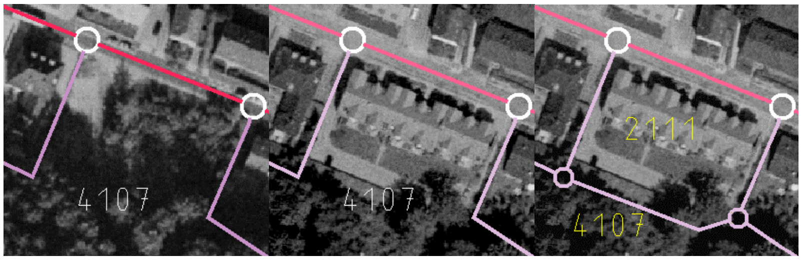

Figure 3: Example for the integrated use of DPWS and GIS for revision purposes. Left: old image superimposed with outdated vector data, centre: new image superimposed with outdated vector data, right: new image superimposed with updated vector data. The different colours and number codes refer to the feature catalogue of the vector data.

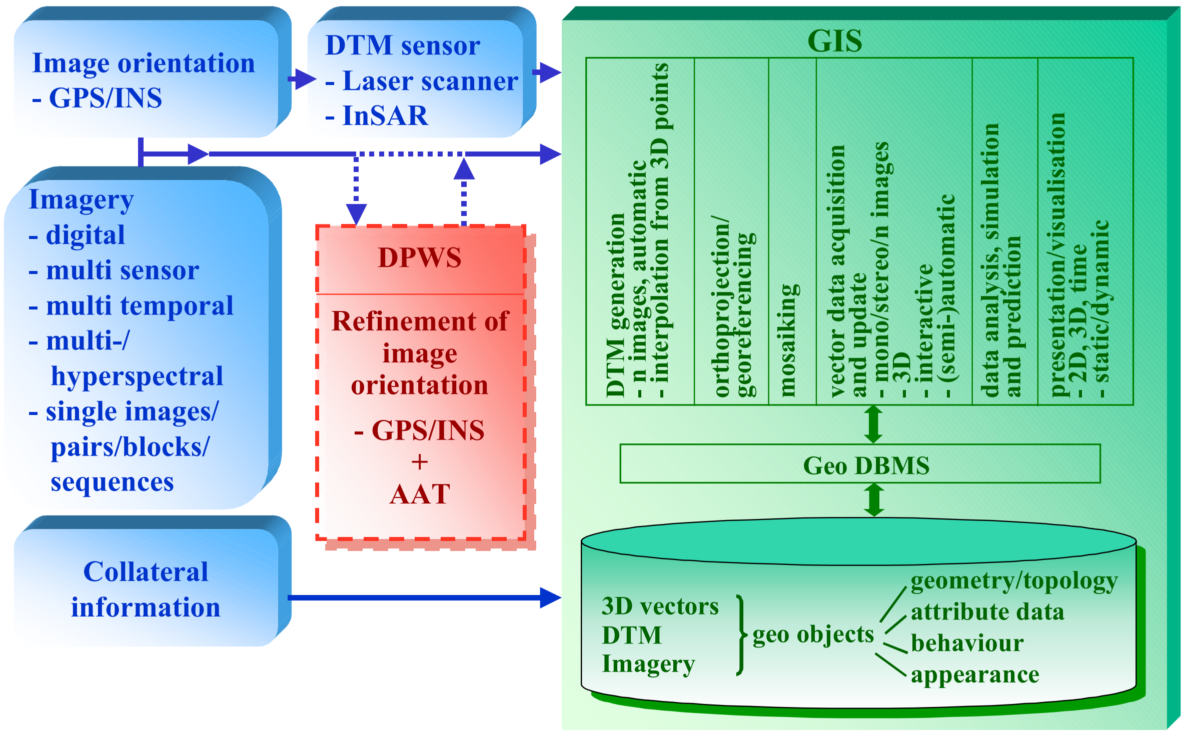

Figure 4: Conceptual design for a tight integration of DPWS and GIS. The DPWS is reduced to performing the refinement of the image orientation as an optional pre-processing step, all other functionality is part of the GIS