INTEGRATING ACTIVE OBJECTS WITH STEREO IMAGES FOR MAP PRODUCTION

P.G. Hardy
Laser-Scan Ltd, Science Park, Milton Road, Cambridge, CB4 0FY, UK.
Web http://www.Laser-Scan.com; E-mail Paul @ lsl.co.uk

Abstract

Photogrammetric feature extraction has traditionally been a standalone activity, feeding data into GIS and mapping systems. New environments however, bring together the previously separate disciplines of photogrammetry, object data modelling and cartography to produce a unified flowline for production of maps, charts, and geospatial data. This paper overviews the capabilities of a modern stereo photogrammetric workstation and of a map production application built on an object-oriented geospatial database, to explore the synergy arising from the close interfacing of the two. The technology, merits and deployment of the integration are discussed.

1 INTRODUCTION

1.1 Why use an object database for mapping ?

Mapping is the art and science of modelling the surface of the Earth, presented conventionally as a graphical illustration. Maps for different purposes exaggerate relevant features while minimising or suppressing irrelevant detail. The term 'map' is used in this paper to cover the whole range of such products, such as topographic maps, thematic maps, charts, plans, atlases, geodata (e.g. CD-ROMs), and ephemeral displays such as Internet web maps.

Producing mapping products used to be a manual draughting task, but now relies on computer cartography. At first this was by compiling the data needed to produce a particular map or chart, usually using file-based feature mapping or graphics software. Increasingly though, the wasteful nature of such one-off capture has been recognised, and there is a move to a database-centric approach in which a geospatial model of the world is captured, stored, and updated. Starting from the database, one can then produce a range of products at differing scales and to different specifications, as described in recent papers on multi-product generation[1,5].

Traditional relational databases are not designed for holding the complex data models and large volumes of variable length data involved in building and ensuring the ongoing integrity of a real-world geographic mapping database. Neither is it easy to produce a range of cartographic products from such data using the static representation facilities found in traditional GIS and mapping software. Now, Object-Oriented (O-O) geospatial databases and associated mapping products have appeared, which provide the technology for a new world of active objects and product-independent geodata storage.

The later sections of this paper cover the O-O paradigm, and put forward its strengths for geographic databasing and map production. They use as an exemplar, the Gothic O-O database and LAMPS2 mapping system from Laser-Scan [2].

1.2 Why stereo photogrammetry ?

Photogrammetry is the specialist discipline of mensuration or measurement from remotely sensed imagery such as aerial photographs or satellite images. Many years of experience in photogrammetric techniques have shown that analysis is much easier when a stereo pair of images is available to allow binocular vision. This is inspired by the same reason that humans (and all animals) have two eyes - visualisation of depth by parallax and perspective allows a much clearer analysis of a view than when seen in 2D, as if with one eye closed. Realisation of the benefits of stereo visual analysis has led to widespread adoption of stereo photogrammetry for map data capture and update.

In addition, although a map is conventionally a flat, 2-dimensional plane, the world in reality goes up hills and down valleys in a 3-dimensional (3D) manner. Superimposed on the natural 3D terrain are manmade artefacts such as buildings, rising above the landscape. For many purposes it is adequate, indeed preferable, to treat the world as flat. However, for some kinds of geographic analysis, the 3D nature of the world has to be considered. To create a full geospatial model of the real world, the terrain and the superimposed artefacts must both be modelled and this increasingly drives the user to holding 3D data, and hence into needing to capture in 3D.

1.3 Why integrate Photogrammetry, Database and Cartography ?

Advances in photogrammetry, spatial databasing and digital cartography all individually contribute to productivity. However, until now progress has been hampered by the difficulties of using a combination of discrete systems. Figure 1 shows the data flows in a traditional combination of a standalone photogrammetric system with a feature-based GIS and mapping system. This should be contrasted with the integrated approach outlined in Figure 2, where Gothic LAMPS2 has been integrated with a modern digital photogrammetric system, to allow 3D database capture and update from stereo imagery, while retaining the advantages of the active object database and mapping environment.

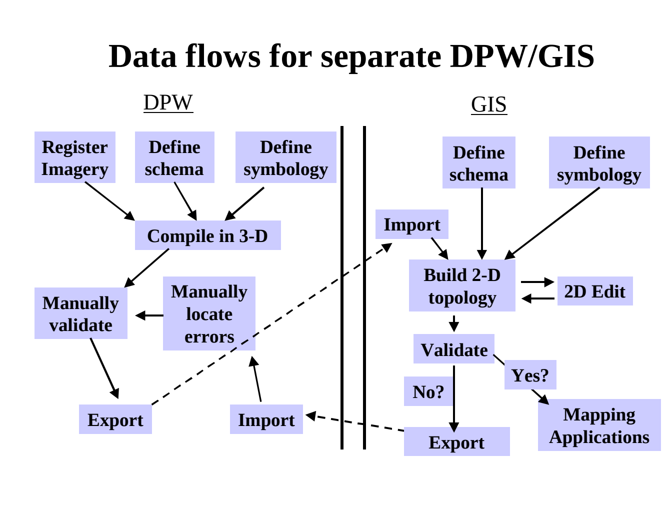

Figure 1 – Separate Systems

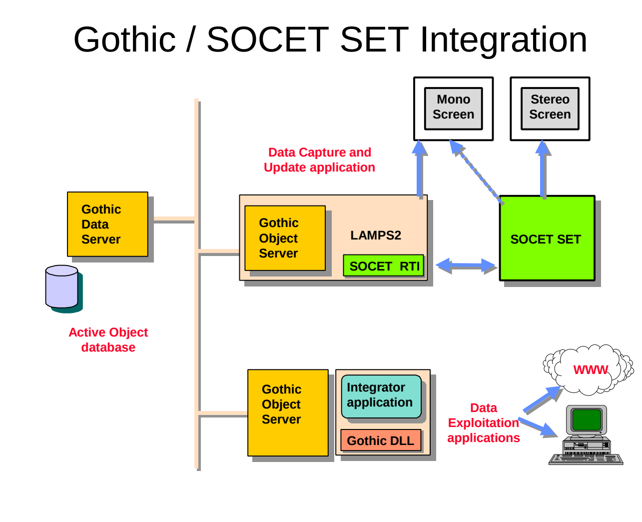

Figure 2 – Integrated model

2 OBJECT DATA MODELLING

2.1 Object-Orientation

In an O-O database, real world entities are abstracted and held as objects. All objects belong to an object class, which defines what values an object can hold. Values can be simple datatypes (integers, strings, dates, etc.) or more specialist types (geometries, locations, rasters, tables, or references between objects).

A key, and defining, concept of O-O is that of methods defined on objects. When a method on an object is invoked by sending a message to the object, the behaviour bound to it is executed, possibly using values and references also held by the object. The ability to define behaviours as part of the database schema, rather than as part of the application, is a fundamental concept of the O-O paradigm.

A further key concept of O-O is that of inheritance, which provides the means to define a new object class in terms of existing classes (Fig. 3). The new class inherits the characteristics (values, references, behaviour methods) of its parent class or classes, unless superseded or redefined. Using inheritance, hierarchies of classes can be created and maintained in a systematic manner.

True O-O appeared in software, has made ground in GIS, and O-O is now appearing in photogrammetry "We have chosen an object-oriented data model to represent spatial objects because of the natural representation of real-world objects in contrast to their representation in a relational database" said Fritsch & Anders in 1996 [3].

2.2 Object Versioning and Long Transactions

One of the problems of traditional relational databases is that their transaction model is designed round the rapid lock-update-unlock scenario common in financial and business transactions. However, completing the update of geodata and mapping for an area is often a long drawn-out process, taking several hours, days, or even weeks. In the interim, the half-updated state must not be allowed to be used for production tasks, but also the unchanged data must not remain locked

The object database, with its encapsulation of all the data and behaviour for each object, lends itself to a different transaction model. In this, each user has a stable view of a 'version' of the dataset. Only changes made by that user are stored in the version, the unchanged objects are accessed from the previous version (Fig. 4). Versioning of datasets within an object database solves the problem of long transactions and allows the sharing of very large data volumes between multiple users needing write access.

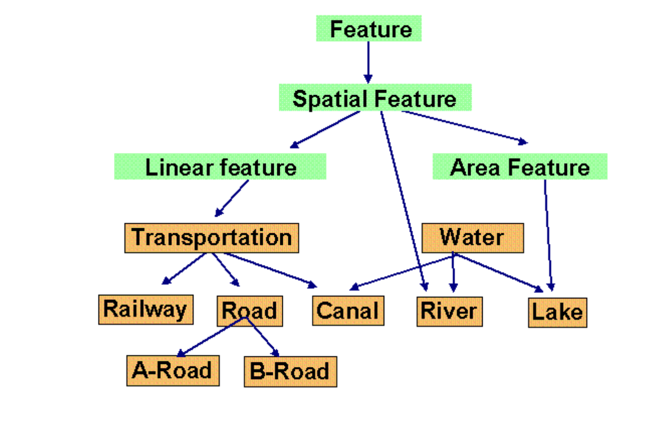

Fig. 3 – Multiple inheritance of classes

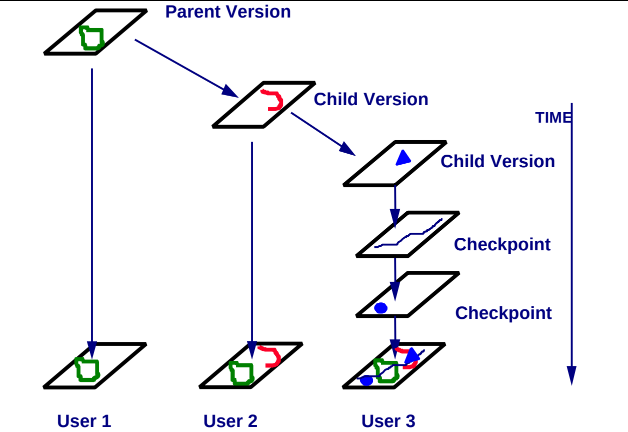

Fig. 4 – Dataset Versions

2.3 Validation methods for data integrity

Data integrity is a major issue for agencies who invest large amounts of money in capturing and maintaining a large geospatial database. The object data model allows the agency to define its geodata logic and business rules as reflex methods in the database schema. This means that the database will enforce these rules as the objects are entered into the dataset, and whenever they are modified. This is done by sending messages to invoke methods:

- A message before the modification is started; so that it can check that it is allowable (e.g. can't move a trigonometric survey pillar unless you are a supervisor).
- A message after the modification is finished, so that it can check that it has been done validly (e.g. can't edit a contour so that it crosses another contour).

If any of the validation reflex methods return a "not OK" result, then the complete transaction is rolled back as if it hadn't started. Note that such validation methods in the database are not just applied during interactive edit, but also during other operations such as bulk data loading from external data sources (e.g. legacy data).

3 ACTIVE OBJECT CARTOGRAPHY

3.1 Active Representation

In an O-O mapping system, the appearance of an object on the screen or on hardcopy is generated at draw time by execution of an arbitrary 'display method' defined on the object class and stored in the database under the direct control of the customer. This contrasts with the traditional approach as indicated in the following table.

3.2 O-O Active Representation	**3.3 Feature Representation**
Dynamic - objects draw themselves	Static - defined by feature class
Objects can draw differently each time	Features always drawn the same
Defined in the database	Defined in the applications program
Can be defined and enhanced by the customer	Can only be enhanced by the supplier
Can be influenced by combinations of attributes	Indexed by single feature code attribute
Can use attributes derived from other objects	Each feature is represented in isolation
Can adapt to external influences like map scale	Not adaptive

The functionality and benefits of active object representation are discussed in [4].

3.4 Multi-product map production

Active representation is not the only useful object-oriented facility to apply when producing multiple mapping products from a product-independent database. Data view selection, map generalisation, furniture generation, and product-specific geometry alternatives are all tools in the armoury of the O-O multi-product map producer. All these are described more fully in papers concentrating on the output side of the flowline [1,4,5].

Object-Oriented generalisation, which puts the intelligence on the objects, is a key technology allowing derivation of tailored products from a product-independent database. This new ability is timely, given the increasing requirements for on-demand mapping, such as for presenting responsive maps in an Internet web browser. Laser-Scan O-O technology (LAMPS2 and Gothic Integrator Java Edition) is at the heart of the AGENT project [6] (Esprit 24939), which is pushing forward the limits of automated generalisation.

4 COORDINATES, 3D, AND TOPOLOGY

4.1 Coordinate storage

The Gothic object database at the heart of LAMPS2 holds its model of the real world as objects that have properties and behaviours. The properties of objects can include attributes, relationships (pointers) to other objects, and geometries (coordinates). Traditionally that geometry has been 2D - (X,Y) or (Lat,Long). Height information has been held at the object level as height attributes, such as contour values, sounding depths, or spot heights. Alternatively, height information for a whole area has been held as a Digital Terrain Model (DTM or DEM), giving the height at each point on a regular grid of samplings over the ground. A Gothic database can hold a mixture of vector objects and raster DTMs, allowing applications such as LAMPS2 to access the most appropriate form of height information.

Recent advances in Gothic and LAMPS2 have extended the vector object geometry capability, allowing the holding on an object of per-point height information (Z-values). This opens up new avenues for building and maintaining true 3D datasets.

4.2 Topology

LAMPS2 has powerful facilities for handling topological structure in spatial data, such as identifying nodes at junctions, determining coincident lines and storing them once as shared links, etc (Fig. 5). LAMPS2 is unique in building and maintaining such topological structure 'on the fly' as editing, digitising, or import is done.

In the real world, topological structure often involves features at different heights, for example where a forest is bounded on one side by a lake (Fig. 6). Many other systems ignore this and just hold (X,Y,Z) coordinates, even for shared linework. In contrast, LAMPS2 recognises the need for shared linework to have multiple heights.

LAMPS2 stores the Z on the feature objects which in turn can point to the link to obtain their 2D coordinates. The Z and the (X,Y) are kept in step by automatic reflex methods which are part of the object-oriented behaviour of the base object classes supplied by Laser-Scan. This separation of the coordinates allows features at different heights to interact topologically and share common linework. It also has the benefit that the optimisations of the Gothic database for 2D geometries still operate on 3D geometries.

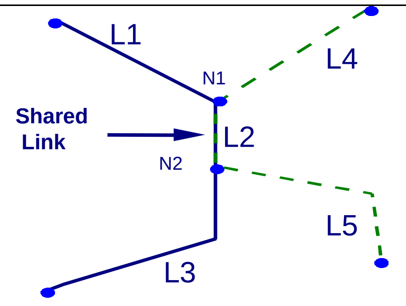

Fig. 5 – On-the-fly topology forming

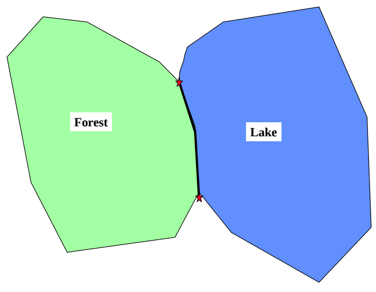

Fig 6 – What height is the shared link ?

5 DIGITAL PHOTOGRAMMETRIC WORKSTATION

5.1 Photogrammetric workstations

The inputs to stereo photogrammetry are a pair of images, either aerial photographs or satellite images. Traditional stereo instruments such as the Leica SD2000 Analytical Stereoplotter [7], or now more commonly stereo workstations such as the LH Systems DPW Digital Photogrammetric Workstation [8] accept such stereo pairs, correct them for the orientation of the sensors, and present them to the user as a 3D window onto the world.

Software from LH Systems, notably the SOCET-SET photogrammetric suite [9] provide capabilities for:

- Import of imagery and control points
- Stereo model preparation (interior orientation, triangulation, rectification)
- Display of mono and stereo views, either in separate stereo monitor or in a stereo window on a single shared screen
- Extract terrain and manmade features into vector data
- Create products such as orthophotos and perspective scenes
- Export vector feature data and hardcopy plot data.

5.2 Photogrammetric workstation software integration

Use of SOCET SET [9] and similar products from other suppliers [10] allows the user to capture 3D features, contours, etc., and to generate DTMs by auto-correlation between the two views. However, many users have already invested much effort and time in building a model of the world using traditional maps, which have been or are being digitised. These users want to take advantage of photogrammetry as a primary data source for update of their database. Other users are undertaking initial capture via photogrammetry but are worried about the quality and integrity of the data they are capturing and want a proven data management system. It was for both these types of user that Laser-Scan has collaborated with LH Systems to offer close integration between LAMPS2 and photogrammetric workstations such as the LH Systems DPW770.

LAMPS2 and the LH SOCET-SET photogrammetric suite share the same workstation (either Unix or Windows NT) and present a unified interface to the user (Fig. 7). The integration offers the following facilities:

- 3D position input in real-time from the stereoinstrument direct into LAMPS2.
- Interactive digitising and editing, direct into the object-oriented spatial database as a data repository.
- Ergonomic cartographic editing tools for database update.
- Object-Oriented integrity and validity controls enforced.
- Stereo superimposition, displaying the 3D object database data over the stereo image.

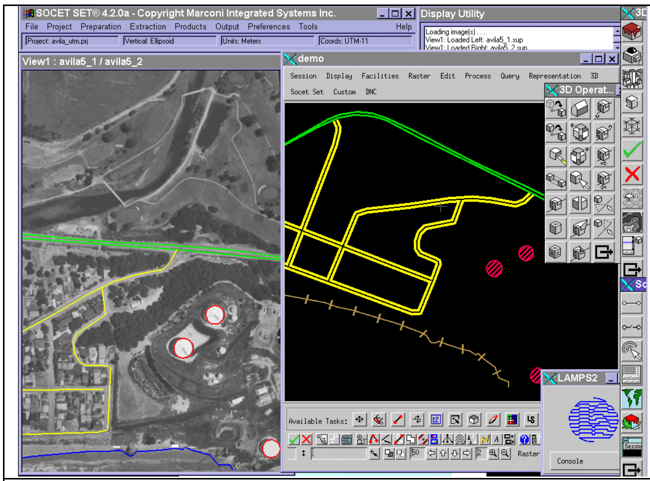

Fig. 7 – Unified screen interface

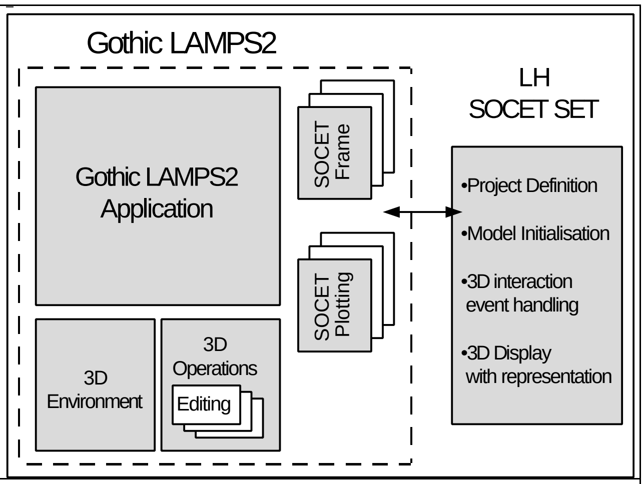

Fig. 8 – Integration block diagram

6 INTEGRATION STRATEGY

6.1 Design Outline

Both LAMPS2 and SOCET-SET are sold as Commercial Off The Shelf (COTS) software packages, but both include development toolkits. As LAMPS2 is the central component of the final user system, this was the software that was enhanced to facilitate the integration of the two packages. Ease of use was seen as an important aspect of the design, and from the start, this criterion was used to ensure that the integration of these powerful software packages did not result in a cumbersome and difficult to use software combination.

6.2 Implementation

The SOCET SET Real-Time Interface (RTI) library is linked into the LAMPS2 program. As well as talking directly to LAMPS2, the RTI talks via an inter-process communications channel to the SOCET SET runtime system. This in turn drives the stereo display and handles the operator events such as button presses.

The main component of the system is the 3D Environment (Fig. 8). This module handles the interface between available operations and inputs from external sources. Modules can register themselves with the 3D environment, which then presents appropriate interfaces and functionality to the user. It is the 3D Environment that controls the passing of inputs (normally button pushes from the user), through to the appropriate editing primitives implemented within the 3D operation modules. The initial implementation provides the 3D operations for digitising (points, lines and areas) and editing functions (move, copy, delete, bridge, append, etc.).

An example operation is the act of digitising a point. The user selects the digitising operation from the interface, e.g., by clicking on an icon in a palette. This action places the environment into the digitising mode. While in this mode four inputs are accepted; add a point, remove a point, accept edit, and abandon edit. The application does not block while in this mode, but if the correct event is passed to the 3D environment, the event is processed.

In this basic point mode, the source of the inputs has very little bearing on the interaction. This is not the case when dynamic feedback is required. When the user digitises a point along a line, a rubber-banded line is required to be shown in the stereo view to give feedback to the user. This dynamic display is requested by LAMPS2 but implemented by the particular application providing the display fronted (in this case, SOCET SET).

LAMPS2 controls all these operations, with SOCET-SET providing the input and handling the 3D display requests. The user (normally using the 3D extraction monitor) initiates an operation to be performed within LAMPS2. On completion of the operation, the object is asked to validate itself. If it passes the checks, then the object is entered into the database. If required, the attribution (population of properties) can take place at this stage. Specialised interfaces make the entering of attributes a simple process - as with geometry capture these attributes are subject to validation before entry into the database.

6.3 Display and Representation in 3D

The representation of data within any photogrammetry system is limited by the display characteristics of the 3D display and the display-list rendering software. In the case of SOCET-SET there are a number of drawing primitives that allow a good quality of cartographic output to be achieved within the extraction monitor. LAMPS2 perceives the extraction monitor as another plot device and uses its cartographic representation facilities to send the appropriate commands to SOCET-SET for it to draw the objects on the screen.

The standard object styles for points and lines supplied with LAMPS2 along with users' own display methods work fine with the SOCET display system. Areas are usually drawn in outline, and text is drawn at the constant height of its anchor point. In general, a simplified concise cartographic representation is used to avoid cluttering the extraction window. Full cartography can always be displayed in the LAMPS2 window if wished (figure 9).

7 DEPLOYMENT

7.1 Deployment by U.S. Military

The first deployment of such an integrated system is in use at the Topographic Engineering Center (TEC) of the U.S. army. Feedback from the initial version has been used to improve user interface and tackle the real-world problems of topology in 3D. TEC realised that 'after the event' validation of x,y,z-data is an even greater nightmare than for x,y data. Hence the strong motivation to build in checks in the capture process.

Building on the TEC experience, flowlines have been developed and systems installed at NIMA for VPF (Vector Product Format) production of FFD and MSDS structured data products. The focus is on use of the O-O validation methods, to ensure that z data captured is consistent and correct. This includes spike detection, clearance checks on bridges, slope consistency and point-in-area consistency.

There is also a rising need in NIMA to model phenomena that can't be expressed in VPF (which only allows a single z for any x,y - the so-called 'z-bust' problem). LAMPS2 has shown that the underlying Gothic object model can model these and that they can be expressed in the Spatial Object Transfer Format SOTF [11], prepared by Laser-Scan for NIMA and recently released to the Open GIS Consortium.

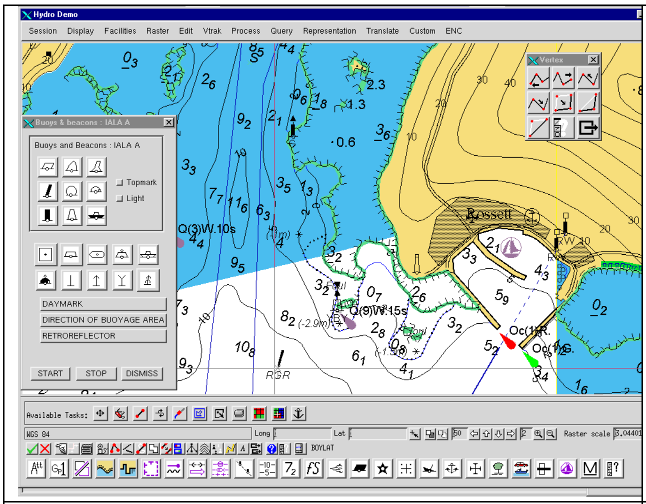

Fig. 9 – Hydrographic data and representation (UKHO)

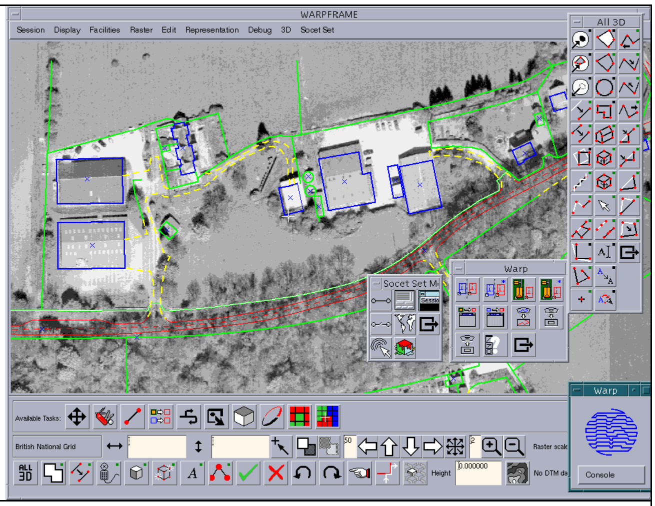

Fig. 10 – Mono imagery warping

7.2 Deployment by U.K. Ordnance Survey

The Ordnance Survey of Great Britain (OSGB) recently started a major project using LAMPS2 to re-engineer the Landline National DataBank (NDB) at scales of 1:1250, 1:2500, and 1:10000. The re-engineering is to build useful structured objects from the previous spaghetti lines. Last year, OSGB also adopted LAMPS2 as its ‘Corporate Editor’, motivated by the need to update/maintain its valuable data in the topologically structured OS96 data model (thus preserving the added value). This corporate editor deployment is now being introduced in the photogrammetry department.

The installation is 11 seats (rising to 30) of integrated LAMPS2 with SOCET SET, to be used for systematic update of the NDB. OSGB do not at this stage use or keep the z data from photogrammetry - they are using stereo imagery because it is easier to interpret than mono. The existing data to be updated is heighted from their existing DTM, then systematically updated from sequences of stereo pairs and put back in the repository as 2D objects.

Away from the integrated SOCET SET workstations, OSGB will also be using standard LAMPS2 with backdrop of mono imagery. LAMPS2 allows local warping of the raster for display to fit the vector data. The 3D editing facilities are still available in this environment, as shown in Figure 10 above.

8 BENEFITS

8.1 Why Object-Orientation for Photogrammetry ?

The particular strengths of O-O in respect to photogrammetry relate to:

- Data storage and retrieval, including object versioning, long transactions, complex data modelling, validity checks and data integrity.
- Data visualisation, including cartographic production, but also representation of the database data superimposed on the stereo view during the extraction or update process.

The following sections expand on this for the two lifecycle stages: initial data capture, and database update.

8.2 Initial Data Capture

During initial data capture, the prime benefits of a closely integrated solution are:

- The visual analysis advantages of stereo photogrammetry allow accurate and speedy extraction of features from the imagery.
- Data capture is direct into the repository dataset, avoiding data loss and multi-step flowlines arising from file transfer between disparate systems.
- Data capture is into the full data model, allowing immediate populating of all attributes and object-to-object relationships at the time of analysis.
- The validation methods of the O-O data model can prevent invalid data being captured, allowing immediate rectification of operator error.
- On-the-fly topology formation creates clean, structured data.
- The active representation capabilities give the operator a cartographic quality view of the captured vector data, allowing immediate feedback on the classification and feature coding of the extracted features.
- Support for multiple display windows on multiple screens (mono and stereo) allows the user to have to hand all the tools needed for ergonomic operation, while presenting an uncluttered interface with maximal graphics working area.

8.3 Update

During database update, the prime benefits are the same as for capture, but additional benefits include:

- Photogrammetric imagery provides up-to-date information about change in the real world, to be incorporated into the master object database.
- The versioning and long transaction abilities allow robust multi-user update access to a shared database.
- The data remains in the database and doesn't become degraded or corrupted by transfer in exchange formats between systems.
- Rapid response and up-to-date products can be achieved by interleaving photogrammetric update with the multi-product generation capabilities of an object mapping system like LAMPS2. In particular, the object-oriented generalisation capabilities can give on-demand mapping needed for today's need for on-demand and Internet web mapping.
- Since the data is retrieved directly from the database for display and update in the extraction environment, the complex issue of conflation of multiple datasets is avoided.

9 CONCLUSION

- The union by close integration of the stereo analysis capabilities of a modern digital photogrammetric system like SOCET SET, with a state-of-the-art object-oriented database and active mapping system like Gothic LAMPS2, gives a synergy beyond the scope of the individual components.
- The fact that these two powerful and complementary technologies can be integrated on commodity hardware means that the historically narrow user base can now rapidly expand.
- The result is a combined system that can provide cost-effective, continually evolving, up-to-date mapping and geodata, mastered in a robust object database.
- Deployments of such an integrated system have been made at the Topographic Engineering Center (TEC) of the U.S. army, and at NIMA for VPF production. Installation is under way at a major National Mapping Agency in Europe.
- The combination also provides a base for ongoing research and development of more complex and powerful 3D topological models and 3D geospatial databases.

10 ACKNOWLEDGEMENTS:

This paper uses overview material from two previous papers "Stereo Images with Active Objects - Integrating Photogrammetry with an Object Database for Map Production", by Cameron, E.C.M and Hardy, P.G., given in ISPRS Commission II in Cambridge, UK in August 1998, and "Integrating Active Objects with Stereo Images for Map production", given at the RICS Geomatics Symposium, Nottingham, UK, in October 1999.

11 REFERENCES

[1] Hardy P.G., 1998, "Map Production From An Active Object Database, Using Dynamic Representation and Automated Generalisation", The Cartographic Journal, Vol. 35 No. 2 pp. 181-189, December 1998, UK

[2] Laser-Scan, 1994, "The Gothic Versioned Object-Oriented Database: an Introduction". November 1994, Laser-Scan Ltd, Cambridge UK. See also up-to-date information on the Internet web pages at http://www.laser-scan.com/.

[3] Fritsch, D. and Anders, K-H., 1996 "Automatic Interpretation of Digital Maps for Data Revision", International Archives of Photogrammetry and Remote Sensing, Vol. XXXI (B4): 90-94.

[4] Hardy P.G. and Woodsford, P. A., 1997, "Mapping with Live Features - Object-Oriented Representation", ICC Conference Proceedings, June 1997, Stockholm, Sweden.

[5] Hardy P.G., 1999, "Active Object Techniques for Production of Multiple Map and Geodata Products from a Spatial Database" , ICA/ACI Conference Proceedings, August 1999, Ottawa, Canada.

[6] Lamy, S., et al, 1999, "The Application of Agents in Automated Map Generalisation", ICA/ACI Conference Proceedings, August 1999, Ottawa, Canada.

[7] Cogan, Luis, Hinsken and Ludger, 1992, "The concept of a Photogrammetric Workstation outlined by the example of the Leica SD2000", International Archives of Photogrammetry and Remote Sensing, Vol. XXIX (B2), Washington.

[8] Dam, A. and Walker, A. S., 1996. "Recent developments in digital photogrammetric systems from Leica-Helava". International Archives of Photogrammetry and Remote Sensing, Vol. XXXI (B2): 66-71.

[9] LH Systems (1997) "SOCET SET User's Manual", Version 4.0.8 of 12 December 1997, San Diego, USA

[10] Petrie, G., 1997. "Digital photogrammetric workstations: a perspective on suppliers and users". Geomatics Info Magazine, 11 (7) 18-23.

[11] Laser-Scan, 1999, Spatial Object Transfer Format, Version 1.2, November 17, 1999, prepared for NIMA (NMA201098-3-0022).

[Revised 2000-03-27]