Stereo Images with Active Objects -
Integrating Photogrammetry with an Object Database for Map Production

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ABSTRACT

Photogrammetric feature extraction has been seen previously as a standalone activity, feeding into GIS and mapping systems. This traditional view is now challenged by the availability of new environments which 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, in order to explore the synergy arising from the close interfacing of the two. The logic and technology of the integration are discussed, and the merits of combining photogrammetry with active objects are assessed both for initial geodata capture and for subsequent map update.

1. INTRODUCTION

1.1 Why use an object database for mapping ?

A map is a model of part of the surface of the Earth presented as a graphical illustration. Maps are produced for different purposes and will tend to exaggerate relevant features while minimising or suppressing irrelevant detail. Producing maps and similar products such as charts, plans, atlases increasingly relies on computer cartography.

In the past such cartography was done by capturing and compiling the data needed to produce a particular map, using file-based feature mapping software, and frequently via photogrammetry. 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, it is then possible to produce a range of products at differing scales and to different specifications [Woodsford 1995].

Traditional relational databases are not designed for holding the complex data models and large volumes of 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.

Recently however, the advent of Object-Oriented (O-O) geospatial databases and associated mapping products provides the technology for this step into the new world of active objects and product-independent geodata storage. The later sections of this paper cover the O-O paradigm in more detail and put forward its strengths for map databasing. They use as an exemplar, the Gothic O-O database and LAMPS2 mapping system from Laser-Scan [Laser-Scan 1994].

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.

For both the above reasons, LAMPS2 has recently been integrated with a modern digital photogrammetric system, to allow database capture and update from stereo imagery, while retaining the advantages of the active object database and mapping environment.

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 object classes. For each class there may be many objects, but each object belongs to only one class. The class defines what values can be held by an object. Values can be simple datatypes (integers, strings, dates, etc.) together with more specialist types (geometries, locations, rasters, tables). Furthermore, objects can hold structural information or references between objects.

A key, and defining, concept of O-O is that of methods defined on objects. These methods are bound to behaviours. 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.

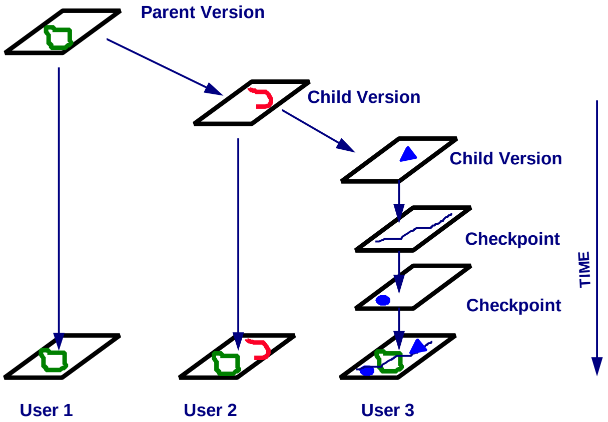
A further key concept of O-O is that of inheritance, which provides the means to define a new object class in terms of existing classes. The new class inherits the characteristics (values, references, behaviour methods) of its parent class or classes, unless superseded or redefined. Using inheritance,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

True O-O has gained much popularity in software engineering and computer graphics [Taylor 1990], and is making ground in GIS. 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" [Fritsch & Anders 1996]. In reality, however, there are still few commercially available systems that support all the key elements to a level that can successfully support large multi-product mapping applications.

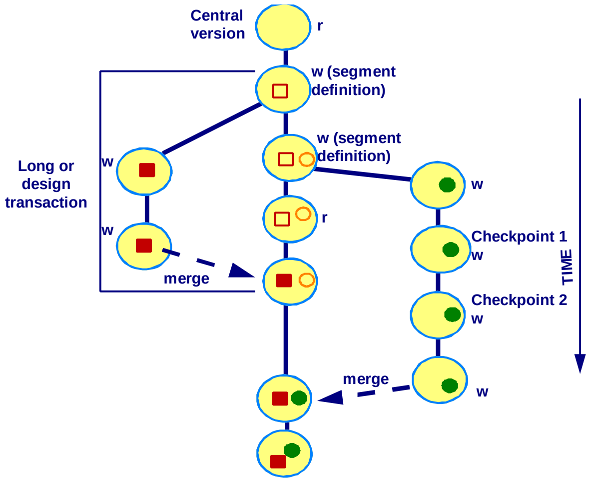
2.2 Object Versioning and Long Transactions

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.



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 [Woodsford and Hardy 1997].



In the diagram above, two users each reserve a segment of a continuous dataset for update, and after several checkpoints (e.g. when they stopped for lunch), the changes are merged to give an updated central (mainstream) version. This is discussed further in [Woodsford 1996].

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.

Whenever an object is being modified, messages are sent automatically to the object at the various stages:

- 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 What is 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.

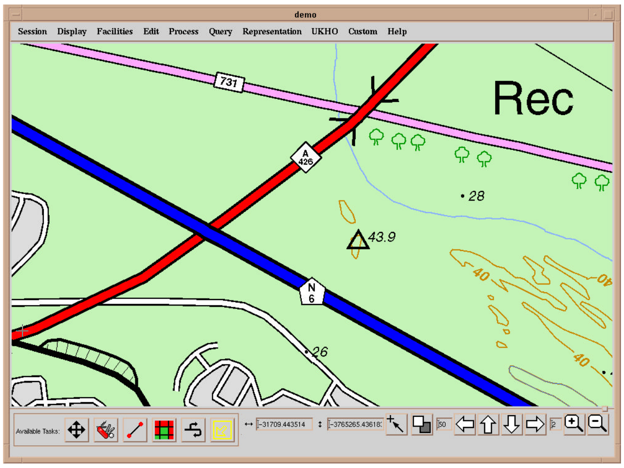
O-O Active Representation	Feature Representation
Dynamic - objects can draw themselves differently each time	Static - defined by feature class
Defined in the database	Defined in the applications

	program
Can be defined and enhanced by the customer	Can only be enhanced by the software supplier
Can be influenced by combinations of attributes	Indexed by single feature code attribute
Can be influenced by attributes derived from other referenced objects	Each feature is represented in isolation
Can adapt to external influences (e.g. required map scale)	Not adaptive

3.2 Results of Active Representation

The following example illustrates the benefits of active object representation, in the production of a topographic 1:50,000 map from a product-independent database. In particular, the following features should be noted:

1. The road number symbols are objects of a single class which have no attributes and no coordinates. When digitised, a pre-commit reflex method defined in the database locates the nearest road object and sets up a direct object reference. Whenever a message is sent to the number object, it follows the reference to determine the road number, road type, position, and orientation. It then uses this information to draw itself with the appropriate text and box.
2. The contour label objects similarly extract height, position, orientation from the contour object, and use it to blank out a section of the contour and draw the label, oriented so that it reads correctly going up hill.
3. The bridge object is a short line object which has its ends snapped onto the road (A425), and therefore shares link geometry for the section. It has no line representation of its own, but repeats the representation of the road to which it is attached, but at a higher drawing priority to ensure that it overdraws the crossing road (731). The display method calculates the position and orientation of the bridge abutments (> <) and draws those also.
4. Roads are drawn as two parts with differing priorities, firstly in black to get the casings, then more narrowly in the infill colour. The priorities can come from combinations of attributes on the road class.
5. The railway cutting, complete with its embankment ticks is generated as needed for scale from the outline of the cutting using a representation generation method.
6. The trig point uses multiple representation derived from combinations of attributes to get both the triangular symbol and the text label for the height.



Base map data courtesy of DOSLI South Africa. Copyright RSA.

The functionality and benefits of active object representation are discussed in [Hardy & Woodsford 1997].

3.3 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 generalisation, and product-specific alternatives are all tools in the armoury of the O-O multi-product map producer [Hardy 1998].

3.4 Map Generalisation

Map generalisation is the science (and art) of exaggerating those aspects that are important for this particular map purpose and scale, and removing irrelevant detail that would clutter the map and confuse the user.

Generalisation has traditionally been a hard task to automate, being dependent on the skills of the human cartographer. People have tried for years to build centralised 'knowledge bases' of generalisation rules, with very limited success. In such systems, the map features themselves have just been passive items containing coordinates and attributes, acted upon by the centralised rules.

In the object-oriented world, this is turned upside down. The map features themselves become objects which have generalisation methods and behaviours defined in the database schema. The application itself becomes much thinner, and contains no knowledge about what, how, or when. It merely provides a framework for invoking and sequencing the generalisation processes by sending messages to selected objects.

Each such object inherits behaviours from its object class definition and from superclasses in its class inheritance hierarchy. These behaviours allow the object to decide for itself what to do when receiving a message to generalise itself, e.g. it can inspect its relationships with its neighbours to decide whether to move itself. However, as the object modifies itself, any objects which are directly linked to it or spatially adjacent can also be told to reassess themselves, so that effects propagate.

The advent of the object-oriented paradigm therefore opens up new strategies for generalisation. LAMPS2 includes an object-oriented generalisation facility which allows the user to define the strategy for generalisation in terms of methods on the object classes [Hardy 1996]. This new ability is timely, given the increasing requirements for on-demand mapping, such as for presenting responsive maps in an Internet web browser.

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), also known as a Digital Elevation Model (DEM). These are matrix (raster) data, 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 for the task in hand.

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. LAMPS2 is unique in building and maintaining such topological structure 'on the fly' as editing, digitising, or import is done.

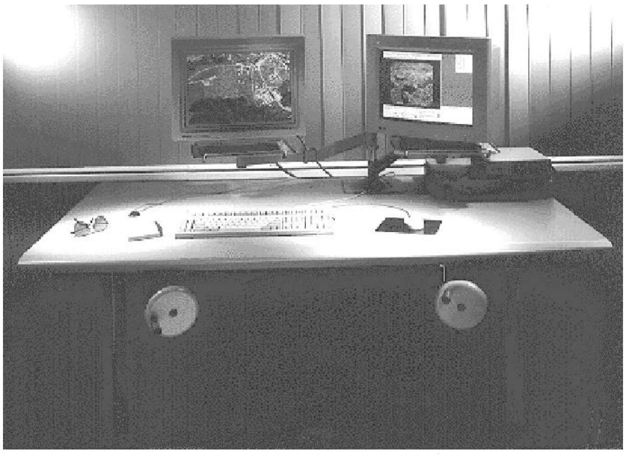
In the real world, topological structure often involves features at different heights, for example where a forest is bounded on one side by a lake. Many other systems ignore this and just hold (X,Y,Z) coordinates, even for shared linework. In contrast, LAMPS2 recognises the need for shared linework to have multiple heights. LAMPS2 does not store (X,Y,Z) coordinates on the link geometry for features with per-point heights. Instead, it 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.

The separation of Z from X,Y also gives a clean implementation architecture for multiple per-point attributes. These are things like additional heights (e.g. upper and lower heights for a cliff), or delta heights (distance to ground from point on roof of building), or other non-height information like capture method flags. In a similar manner to the Z information, these too should be stored on the feature object not on the topology link object which holds the X,Y coordinates.

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 [Cogan 1992] or now more commonly the LH DPW Digital Photogrammetric Workstation [Walker & Petrie 1996] 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.



Leica DPW770 Stereo Workstation for LAMPS2 Integration

Leica/Helava software, notably the SOCET-SET photogrammetric suite [LH Systems 1997] provide capabilities for:

- Import of imagery and control points
- Stereo model preparation (interior orientation, triangulation, rectification)
- Display of mono and stereo views
- 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 [Dam & Walker 1996] and similar products from other suppliers [Petrie 1997] 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 Leica DPW770.

LAMPS2 and the Leica Helava SOCET-SET photogrammetric suite share the same workstation (either Unix or Windows NT) and present a unified interface to the user. 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.
- 3D vector stereo superimposition, displaying the object database data over the stereo image in 3D.

6. INTEGRATION STRATEGY

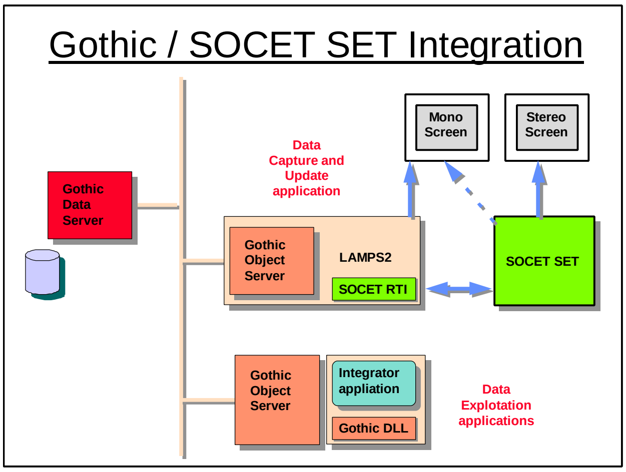
6.1 Design Outline

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 criteria 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 Architectural Design

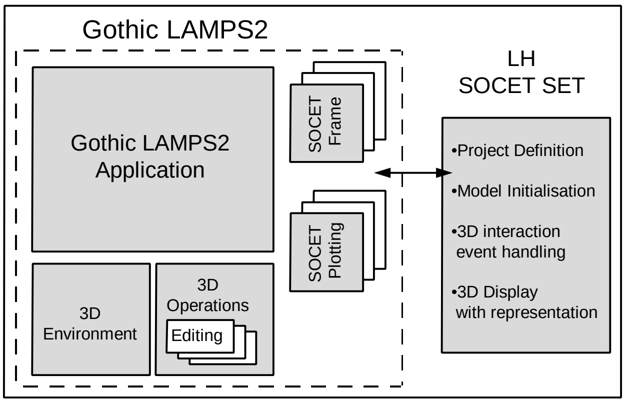
The SOCET SET Real-Time Interface (RTI) library is linked into the LAMPS2 program. As well as talking directly to LAMPS2, the RTI talks via an inter-process communications channel to the SOCET SET runtime system. This in turn drives the stereo display and handles the operator events such as button presses.



6.3 Implementation

The changes made to the LAMPS2 application were done in such a way that the 3D editing environment presented to the user was generic and equally applicable to different configurations. Two initial environments are available to the user, one supported from solely LAMPS2 and the other using the SOCET-SET application. The internal 3D environment is unaware of where the inputs are coming from. A thin layer within the application initialises the appropriate functionality depending on the available software components.

Referring to the diagram below the main component of the system is the 3D Environment. 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, 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.

6.4 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.

7. BENEFITS

7.1 Why Object-Orientation for Photogrammetry ?

The description of O-O given in earlier sections applies to almost any geospatial data application [Woodsford 1995b]. 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.

7.2 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.
- The data capture is direct into the repository dataset, avoiding data loss and multi-step flowlines arising from file transfer between disparate systems.
- The 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.
- 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.
- The 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.

7.3 Update

During database update, the prime benefits are as for capture, but also:

- 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 get 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.

8. 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 which can provide cost-effective, continually evolving, up-to-date mapping and geodata, mastered in a robust object database.

The combination also provides a base for ongoing research and development of more complex and powerful 3D topological models and 3D geospatial databases.

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