SURFACE RECONSTRUCTION

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ABSTRACT

Classical 3-dimensional photogrammetry has traditionally relied on stereoscopy to obtain the geometry of surfaces. This focus on stereoscopy has recently been broadened to include interferometry with radar sensors, single image measurements in urban modeling, shape-from-shading to refine the surface description, or ranging in planetary and industrial settings. The generalization of the problem domain occurs also from a mere consideration of surface geometry to include surface visualization. This in turn causes one to need surface properties other than geometry. We review current thinking and present some recent study results, particularly with satellite remote sensing images and industrial object reconstruction.

ZUSAMMENFASSUNG

Die klassische Photogrammetrie fokussierte sich auf die Oberflächenmessung mittels Stereoskopie. Dies hat sich in den letzten Jahren zu einer etwas ganzheitlicheren Betrachtung erweitert. Interferometrie, Einzelbildmessung in urbanen Anwendungen, Shape-from Shading, Lauflängenmessung in planetaren und industriellen Problemstellungen und anderer Methoden der Geometrieerfassung werden durch die Generalisierung der Betrachtungsweise um die Frage der Visualisierung ergänzt. Dies verursacht ein Interesse an den nicht-geometrischen Eigenschaften einer Oberfläche. Wir betrachten diese neue Denkweise und zeigen einige neuere Arbeitsergebnisse, besonders aus dem Bereich der Satellitenfernerkundung und der industriellen Oberflächenerfassung.

1 THE EVOLUTION OF SURFACE RECONSTRUCTION

The concept of „surface reconstruction“ traditionally consists of the creation of a geometric model of a surface by stereo-photogrammetric means. We have entered an age of coping with vast amounts of digital visual data where this traditional concept no longer applies. Instead we deal with a model of a surface in terms of (a) a digital data base describing a surface's geometry and denote this a the geometric model; and (b) an accompanying description of surface properties such as texture, roughness or material properties; (c) combining such data with a so-called „graphics pipeline“ to serve specific applications. Modeling and rendering become thus elements of one and the same system. The underlying ideas apply whether one deals with an entire planet such as Venus or with microscopic structures such as the surface of steel probes.

1.1 From 2.5-Dimensional to 3-Dimensional Surfaces

Photogrammetric tradition focusses on the surface of the Earth. Information is extrated from aerial photography and the object has a wide extent in planimetry but only a small range of elevation. This is the reason why one often refers to terrain as a 2.5-dimensional object. A vast range of literature and procedures exists to automatically extract the surface shape of terrain from aerial photography. The result is a respresentation of the so-called „bald Earth“. The procedures work successfully, provided the bald Earth is accessible and not obstructed by objects such as trees or man-made objects.

Recently this problem domain has been generalized to one where fully 3-dimensional objects need to be modelled. In the topographic application this may be objects on top of the bald Earth. In industrial settings this may be parts that need to be inspected. In entertainment or architecture this may be the inside of buildings. In medicine this may be the anatomy of a human. In physics this may be the nano-structure of objects. The very well-defined topographic application of traditional photogrammetry has therefore recently been expanded significantly and so has the range of methods that are applicable to surface reconstruction.

1.2 From Stereoscopy to the Reconstruction of Surface Geometry

Photogrammetry has tradionally relied on stereoscopy for modeling the geometry of a topographic surface. Also industrial and architectural applications have traditionally relied on stereoscopy. A more modern view is not focussing on stereoscopy to reconstruct a surface but to focus on the goal of surface geometries and on those methods that are best suited for a particular need. As a result one may find today commercial systems for modeling smaller industrial objects or human faces that rely on non-stereoscopic ranging or even tactile reconstruction systems. An industry not much smaller than that of photogrammetric equipment has recently emerged that will feed the geometry of objects into computer graphic rendering systems. These may be based on magnetic, acoustic or optical tracking of a cursor in 3-D space. It may employ ranging, or use structured light. Table 1 is an attempt at summarizing the range of modeling techniques for 3-dimensional objects.

- Stereoscopy
  - optical and active echo-ranging, electron-microscopes
- Tactile profiling
  - magnetic tracking
  - optical tracking
  - acoustic tracking
- Structured light
- Exploiting geometric constraints in single image
- Ranging with lasers and radar altimetry
- Interferometry
- Shape-from-Shading
- Use of shadows, layover
- Photometric stereo
- Tomographic imaging

***Table 1:** Techniques Used for Extracting Object Surface Geometry*

1.3 Surface Radiometry

The extension of reconstruction from a purely geometric to a global view of surface properties is a result of the transition to so-called „Digital Visual Information“ to encompass both „Image Processing“ and „Computer Graphics“. The surface consists of the bald reference object, objects placed on the bald reference surface, information about the surface's reflective properties such as color, specularity and texture. Methods of assessing the surface radiometry are well-understood in remote sensing. The brightness information obtained in an image needs to be inverted to a measure of reflective properties of the surface. This benefits from multiple looks at each surface point in different spectral channels as well as from different vantage points.

The assessment of texture is most commonly accomplished from photographs. The object geometry is being modeled by polygons and each polygon receives a photographic facet. This facet needs to be made independent of effects of the illumination and viewing direction valid at the time of imaging.

1.4 Rendering a Surface

Clearly surface reconstruction is a function of its application. Traditionally photogrammetry has been used for topographic mapping so that the resulting maps are available for navigation, orientation and planning. With the advent of computer generated images and computer graphics the surfaces also are being used for rendering. The problem is then expanded by issues of illumination, viewing position and viewing direction. The map as traditional product is being replaced by geometric and radiometric object models and by the graphics pipeline, to feed the softcopy visualization of an object.

2 STEREOSCOPIC RECONSTRUCTION

2.1 A Systems View

Stereoscopy is the best understood method of surface reconstruction in photogrammetry. The traditional view decomposes stereoscopic machine vision into a set of individual worksteps (Table 2).

1. Image orientation
2. Image matching
3. Preliminary surface definition
4. Match verification and acceptance
5. Final surface representation
6. Gridding
7. Data formatting

***Table 2:** The stereoscopic process flow.*

The most widely discussed aspect of stereoscopic machine vision is image matching. The least understood is verification and acceptance of a surface point.

2.2 Image Matching

The search for homologue features in overlapping images has received most of the attention spent in the past on automated digital stereoscopy. A recent authoritative presentation is by Förstner (1993). The matching domain is being addressed essentially in image or object space and in terms of feature matching or area-based matching. The last 25 years have seen a proliferation of techniques that focus on the speed of matches, the robustness and independence of radiometric and geometric disparities in images, the pull-in range, i.e. the ability to find a match even if the geometric differences between two images are large, the smart prediction of presumed match locations, the idea of using resolution pyramids in a hierarchical approach, the optimization of similarity measures, e.g. in terms of a least squares estimation of the match location, the combination of geometric and radiometric parameters to determine a match, the reduction of the dimensionality of the problem by constraining the search areas along epipolar lines.

The matching ideas further could be grouped into those applicable when nothing is known about the object and the camera (Zhang et al., 1995); when metric cameras are used and the orientation of the cameras in 3-D space is known; when the object is fully 3-dimensional and has many hidden and occluded elements; when structures exist that can be approximated by polygons, e.g. when looking for buildings in an urban environment; when the radiometry interferes with geometry such as in active echo-ranging systems (radar and sound).

The matching accuracy is variously reported as ranging between ± 2 pixels in highly dissimilar image pairs such as those obtained with a speckle-infested radar system to ± 0.05 pixels or better when sharply defined, rotationally symmetric objects can serve as homologue features in overlapping, well-illuminated stereo photography using retro-targets.

2.3 Verification and Quality Control

The most significant limitation to successful stereoscopic machine vision is one's ability to reliably verify and accept a surface point. The effort to determine that a match point is consistent with the expectations and with neighboring match-points often exceeds by far the effort to obtain a match at all. The success in identifying match-points is traditionally being improved by looking for matches at selected image locations obtained through interest operators. Yet, these concepts have not been able to produce working stereoscopic machine vision systems that will operate as reliably as a human operator can, except for very well constrained scenarios.

3 OBJECTS IN SINGLE IMAGES

3.1 An Applications Scenario

The advent of computer graphics and digital entertainment as well as a refined need for disaster preparedness, training and simulation, planning and citizen participation is creating a market for fully 3-dimensional geographic information systems of urban areas. The „CyberCity" needs tools to reconstruct roofs and buildings (Gruber et al., 1995). It is not necessary to rely on stereoscopic machine vision to reconstruct buildings and building boxes from photographs. Braun (1993) has shown that the knowledge that a building's walls are vertical and that rooflines typically are horizontal can be exploited when using a single aerial photograph. This process of identifying building boxes and attaching roof shapes from single images revives traditional geometric concepts that were originally developed at the turn of the century. At the current time, however, buildings can be extracted automatically from single aerial photographs or under minimal manual control.

3.2 GIS and Aerial Images

In industrial urban areas one can depend on the availability of a 2-dimensional geographic information system in which the third dimension may be available as an attribute. Therefore one will know the footprint of buildings and one will have an elevation measure attached to each building. This can be used to project the footprint and a prediction of the roofline of a building into an exterially oriented aerial photograph. The photograph itself then serves to first verify the geometric information in the GIS and second to improve the geometry and detail of its information. Gruber et al. (1995) have shown a process by which a 2-dimensional GIS and single images can serve to develop building boxes in a process that is similar to the work of Braun (1993), but includes the information of the GIS and is automated.

3.3 Structured Light

Of course the application scenario with „CyberCity" is not the only one in which constraints about the objects permit one to rely on single images. They can also be used when combined with a proper illumination system to reconstruct surface shapes. This classical approach in machine vision is used in industrial applications. Structured light may employ a sequence of parallel planes of light and dark that are projected onto a surface. If it is plane then the intersection with the planes of light result in straight lines. Deviations from straight lines are a measure of a deviation of the surface from a plane. Successful applications of structured light sometimes also combine it with stereoscopy. This may on one hand help in resolving ambiguities, and it may on the other hand improve the accuracy. Structured light's limitations may be the difficulty of obtaining well-defined transitions between light and dark.

4 RANGING

4.1 Laser Ranging and Radar Altimetry

Ranging is applicable in the robotics environment when the distance to an object needs to be known. The planetary guidance of a landing spacecraft may use ranging to determine the absence of obstacles. An automated vehicle may determine its distance from an object by laser ranging. Systems exist that will use a single point source and scan the object along profiles. Multiple sources may be used to scan multiple profiles. The concept of „laser radar" measures the run-time from the source to the object and the direction in to which the energy was transmitted and from which echoes were received. These ideas are also the topic of NASA-concepts for a satellite-based topographic mapping system. The result of a laser range finder is a collection of surface points that are irregularly spaced and potentially noisy. Ranging of course is also the subject of altimetry. This is the traditional planetary tool to determine the shape of a surface. On Earth altimetry addresses the shape of the water bodies. The footprint of a radar altimeter is fairly large and one typically assumes that the first echo to arrive at the antenna is from the nadir. This assumption is only correct if the surface is smooth. In accentuated terrain the first echo may be from a point off to the side. Planetary altimetry suffers from ambiguities such as those obtained on Venus with the Pioneer and Magellan missions, when observations are made in mountainous terrain.

4.2 From Points to Surfaces

Ranging as a data collection mechanism needs to be complemented by a resampling technique that converts the surface points to a continuous surface. Two issues exist: first, that the noise in the data be filtered and that a smooth surface results from a rough point cloud; second, that a data structure comes into existence that actually represents the surface as opposed to an unstructured collection of points. The transition from points to surfaces is trivial if the underlying object is smooth and if the object represents a 2.5-dimensional situation. The problem becomes difficult when a fully 3-dimensional situation exists. We will discuss this further in Section 9.

5 SHAPE FROM SHADING

5.1 Basic Idea

Shape-from-shading is a traditional technique of machine vision to obtain information about the local surface shape given the variations in image brightness. It has traditionally been applied in a controlled illumination environment, e.g. when a robot has to select among various objects presented in a bin.

Surface properties of the material are well-known, the illumination sources and the vantage point are also known with respect to the object. Under those constraints the surface can be reconstructed. However, in principle shape-from-shading is an underdetermined problem. The brightness of a surface cell can be obtained from an infinity of surface orientations. To overcome the ambiguity one needs to impose constraints on the surface. Those are boundary constraints in combination with integrability.

The extension of traditional shape-from-shading as it is known in industrial inspection and robot guidance to the mapping of planetary surfaces was motivated NASA's Magellan mission to planet Venus. Traditionally radar images have been converted to geomorphological products also on planet Earth by exploiting the variations and brightness and darkness in a radar image. „Landforms" have thus been reconstructed by simply exploiting grey values. This can be mechanized by changing the traditional shape-from-shading ideas to be applicable to radar images. Frankot and Chellappa (1987), Kirk (1987), Thomas et al. (1991), Wildey (1986) are the pioneers of this approach. Almost without exception previous work has addressed single images. Thus a geocoded radar image is the starting point from which variations in brightness are inverted into variations of surface slope.

Most recently the ambiguities introduced by unknown surface reflectivity properties in radar images have been tackled by exploiting redundancy in the image coverage. Images taken with different illumination directions are combined and an attempt is made to simultaneously solve for surface slope as well as surface reflective properties. The accuracy of the result is currently not well understood.

5.2 An Application

In NASA's Magellan mission to planet Venus an individual single image coverage was originally planned to be obtained of at least 70% of the planet. The surface shape was essentially only measured by means of an altimeter. The spacing of altimeter observations was to be about 13 km. The size of the radar image pixels was 75 m. Clearly the topographic relief from altimetry will not properly model that which is evident visually from the radar images. Therefore the idea was to apply shape-from-shading to the radar images. When Magellan's satellite survived the initial period of obtaining a complete image coverage of the planet, a second set of images, and later on even a third one, were produced from different illumination angles. As a result many of the areas on the planet are covered by three images. No techniques exist at this point to actually combine the three images.

One needs to begin by removing the geometric disparities so that then a multiple image shape-from-shading approach can solve for detailed surface slopes as well as surface radiometry. This work is currently being pursued but conclusions are still pending. Shape-from-shading from individual coverages or from stereo images that are very similar exist. However, in a viewable stereo pair the angles of illumation are similar so that the surface properties are not sufficiently determined and an ambiguity continues to exist since the surface property is unknown.

6 INTERFEROMETRY

6.1 Background

Radar interferometry has two historical roots. The first one is from radio astronomy using Earth-based antennas to bounce radar signals off the surface of Mars or Venus and receiving the echoes on two antennas that are spaced apart on Earth. This work started in 1964 (Goldstein, 1965). The second historical root is airborne radar imaging for military applications. As described by Graham (1974) this has become originally a technique based on analogue electronic processing. Both the radio astronomic and the airborne imaging developments converted into a digital signal processing domain by the early 1980s. Satellite radar interferometry was first attempted from two images taken with Seasat (1978). This opened an entirely new field of study: the reconstruction of topographic relief from repeat passes of a satellite over the terrain with orbits only a few 100 meters apart.

Independently the military has developed enormous skills in processing echoes received at multiple antennas on an aircraft. This may involve 4 to 8 antennas, all feeding echoes into a signal processing device, mostly attempting to differentiate moving from stationary objects as an aircraft passes over an area of interest. This has lateley been expanded into single pass interferometry for the detailed reconstruction of surface shape from an airborne sensor. Currently commercial ventures may be positioning themselves to exploit this technology aboard low-cost aircrafts to serve as an all-weather alternative to stereoscopic aerial photography. Success of this single pass interferometry with multiple antennas (a minimum of two spaced apart in the direction of an aircraft's wings) depends on the simultaneous availability of an accurate positioning system for the aircraft. The major limitation of this airborne approach is the need to have a precise measure of the direction of the interferometric base, which is the vector in 3-D space extended by the two antennas. There are currently no good solutions available for the determination of the direction of that base, while the position is being determined by GPS.

6.2 ERS-1 and ERS-2 in Tandem, SIR-C

The European Space Agency's remote sensing satellites 1 and 2 (to be followed by Envisat from 1998 forward) have stimulated an enormous interest in exploiting repeat pass interferometry from satellites. Because of the stability of orbits, the need for complicated motion compensation (that is needed from aircraft sensors) and the difficulties of precisely knowing the interferometric base vector are greatly reduced. This makes repeat-pass interferometry from satellites a very attractive and inexpensive technique that essentially uses nothing but signal processing with the regular radar image pixels to obtain an accurate measure of topographic relief.

The difficulty that the terrain changes between two passes of a satellite are overcome by having ERS-1 and ERS-2 operate in tandem i.e. they traverse over an area of interest within minutes of one another rather than within days or weeks of one another. The entire globe has now been covered multiple times only subject to receiving antennas on the ground actually collecting the data as they are being transmitted from the satellite. The processes for repeat-pass interferometry are fairly straight-forward. As a result there are many centers of excellence that are capable of operating with this technique. The difficulties are in those areas where no useful information can be obtained. This may be in areas of image lay-over or image shadows, and it is in areas where the surface reflectivity is mirror-like (with very smooth surfaces, where no echoes are being sent back in the direction of the antenna) or where the coherence of the echoes is marginal or fully destroyed, which may be the case where excessive volume scattering occurs.

However, successful interferometry has been shown even in cases that only recently were considered to be highly risky. This includes mapping the surface of ice sheets and, by differtial interferometry or by exploiting the geometric shape that may be known from other sources, the motion of ice sheets can be measured.

The accuracies of repeat-pass interferometry from satellites can be defined by the elevation sensitivity of the radar system and that is in the range of ± 2 m, given an 12.5 m pixel. The accuracy itself is much lower and is a result of the uncertainities in the orbit and in the interferometric base vector. As a result one typically has accuracies reported in the range of ±15 m or so.

The best of all options would be a single-pass satellite interferometry system. This is being envisaged for a reflight of the Space Shuttle's SIR-C sensor. The highest accuracy would be obtained if the uncertainities about the base vector could be eliminated. That is the case if two antennas are carried on one spacecraft. The idea of a SIR-C reflight on board of the Space Shuttle has been approved by NASA; the timing of the interferometric reflight to cover the entire globe within a few days by interferometric observation is still uncertain.

7 USING RADAR IMAGE LAYOVER

7.1 Layover

An example of an very subtle and difficult element in radar surface reconstruction is the problem that from satellites the look-angle off-nadir is fairly small and ranges from 20° to 45°. As a result areas with high mountains where the elevation information is of greatest value are laid-over. Layover is an effect that occurs when the incidence angle is smaller than the slope. In steep terrain where mountain sides may have inclinations of 30° or more and rocks may be much steeper than that, layover in images is a frequent occurence.

The images in the layover are useless. Interferometry is not applicable. Stereo-viewing is also marginal. As a result vast areas of the mountainous surface become non-observable from satellites, since they need to look with small incidence angles.

7.2 Using the Layover to Define a Slope

To overcome this problem one can develop techniques to automatically identify layover areas in radar images. This is possible when multiple images exist, e.g. from stereo-coverage at different incidence angles. Layover areas are typically bright since they are facing the antenna. A feature that is laid-over is identifiable from stereo-coverage because it is wider in the steeper looking image than in the shallower looking one. A non-laid-over slope would manifest itself in the opposite manner. Knowing that a feature is laid-over in one image, namely the steeper one, leads now to two potential solutions for the slope, depending on whether the second image is laid-over as well. That cannot be decided unambigiously. An opposite-side view from an ascending orbit (if the stereo-views were from descending orbits) can help to resolve the ambiguity. Techniques to automatically employ layover to refine a topographic model of the terrain are currently being developed. A major application would be on planet Venus. However, also in highly mountaineous terrain on Earth it might be applicable to ERS-imagery.

8 FUSION

8.1 The Basic Idea

Fusion is a novel concept in machine vision that suggests that multiple image and multiple methods are being used in concert to obtain specific information of interest. The implementation of this basic idea is very applications-dependent. An industrial setting may employ a vastly different solution to that which may be useful for satellite remote sensing. The combination of shape-from-shading, structured light, stereoscopy, ranging, etc. may be considered a toolbox in which the industrial robotics environment will extract a combination most appropriate for specific domains. The satellite remote sensing application may use a combination of shape-from-shading, stereoscopy, interferometry, and exploitation of shadows and layover and apply this to a suite of image coverages of a given terrain in the optical and radar sensor domain.

8.2 A Strategy for the Fusion of Reconstruction Methods

Given the application-specificity of fusion any common strategy will have to remain on a very generalized level. To take the example of topographic surface reconstruction from satellite sensors we propose that the methods of stereoscopic measurements, shape-from-shading, and interferometry be combined with optical surface classification.

The procedure would need to match the individual images to one another so that an object area's properties are reflected in a set of identifiable pixels in the image. One therefore would want to exploit geometric disparities in the stereo process to create first a DEM, then a stack of co-registered terrain-corrected images. The DEM used for the co-registration could be obtained by interferometry. Therefore interferometry and stereo might complement one another in areas where one would work and the other not. Once the geometric disparities are removed, shape-from-shading can now be used on that image stack to extract further detail of the surface geometry and radiometry. Those properties may be obtainable by classification from optical data and may then be verified and detailed by the microwave observations.

This is very specific to remote sensing of terrain. An entirely different approach may exist if a spacecraft needs to navigate in the final approach to a planetary surface. In that event ranging may be combined with single image shape-from-shading or stereoscopy. Yet another strategy may be developed in a robotics environment where a vehicle needs to navigate in a known factory environment.

9 FROM POINT CLOUDS TO SURFACES

9.1 The Problem

The traditional topographic mapping which results in a digital elevation model employs a gridding method to convert irregularly spaced surface points into a pattern of regular points that produce a square or triangular mesh surface. The process is made difficult only by the need to filter out erroneous or noisy observations.

The problem is vastly different when a truly 3-dimensional object needs to be modelled. In the example of a point cloud describing a hand it is not trivial to decide which surface points should be connected and should become nodes of polygons. The fingers of a human hand may represent a different topology than the toes of a duck. One has the added difficulty of converting a cloud of surface points into a topology that is consistent with the object. Traditionally the only information available about a surface are the irregularly spaced points with their XYZ-coordinates. One has not, so far, begun to augment the bare point clouds by surface normal vectors. Such information would be available from the machine vision element of the process, and one could obtain the surface normals in a shape-from-shading process.

9.2 Example for a Solution

The methods of sorting through a cloud of points and of finding their topology along the surface could be based on selecting the nearest point. This of course may create holes in the surface. It may also connect points that topologically should not be connected, as can easily be seen when modeling fingers on a hand.

The „alpha“ shapes are a recent development that starts out from individual points and creates surfaces from them. The idea of „balloons“ resembles the approach that has come from tomography where the individual voxels are being searched for surfaces that may be on the outside of the object. In this case points are being replaced by balloons which touch one another as the radii increase. The resulting object has a surface that is created from the overlapping balloons. This kind of approach has been extensively tested with point clouds representing a human head and another cloud representing an entire statue of a Habsburg emperor (Uray et al., 1995).

10 REALISTIC VISUALIZATION

10.1 Geometric Detail versus Surface Texture

The accuracy with which a geometric model of an object needs to be created depends on the application. In the event of an object to be visualized and rendered, that accuracy may be traded-off with the detail at which surface properties are known. If a photographic texture of a face, a building facade or a tree exists, one may not have more geometric detail than an ellipsoid for the human face, a cube for a building, and a plane for a tree. This consideration may be in contrast with the accuracy at which topogrpahic relief is being mapped. Yet visualization of a landscape again may require very little geometric detail if the bald Earth is accompanied by the surface cover and by objects placed on the surface.

The use of 3-dimensional surface geometries to support visualization and rendering is of increasing importance. Not least do we find an increased interest in the entertainment industry which is rapidly developing into a very large application for computer graphics and image processing.

10.2 Measuring Surface Properties

The surface properties are needed to relax the requirements on geometric detail. They are also needed to provide a description of reflection properties. The response to illumination in turn does not need to be known very well if the surface texture is observed and available. The reflectivity of a surface can be measured. Photogoniometers and methods analogous to remote sensing classification can be used to obtain the response of a surface point to various illumination directions. A promising approach to measure surface property is based on photography. Multiple photographs are being taken at multiple illuminations of a given surface point and the reflected light is being extracted from the grey value in the photograph.

Image simulation is not only a topic of computer graphics and rendering for human consumption but may also be a tool in image analysis. One example is shape-from-shading where a shape needs to be computed and refined from differences between a simulated and real image. Simulation also is useful when trying to overcome the dissimilarity in image matching. Gelautz et al. (in print), Kellerer et al. (in print) have shown how opposite-side radar images can be matched using image simulation based on a digital elevation model. The difference between an actual image and such a simulation can be an input to the measurement of surface properties. Differences between image and simulation can be explained as a result of variations in the surface.

10.3 An Example of a Room

The use of geometric modelling of objects with subsequent rendering is illustrated by more than 60,000 polygons describing the geometry of an office. The geometry surface properties of each polygon have been determined from photography. Visualization of the room is now a result of raytracing and a method called „radiosity“ (Karner, in print). Raytracing serves to determine the mirror reflections; radiosity is a model to compute the distribution of light in a room given well-defined light sources. Raytracing is depending on the position of a viewer, radiosity is not. Figure 10.3 is a rendering of that room that has been shown as a photograph in Figure 10.1, and as a wireframe rendering in Figure 10.2.

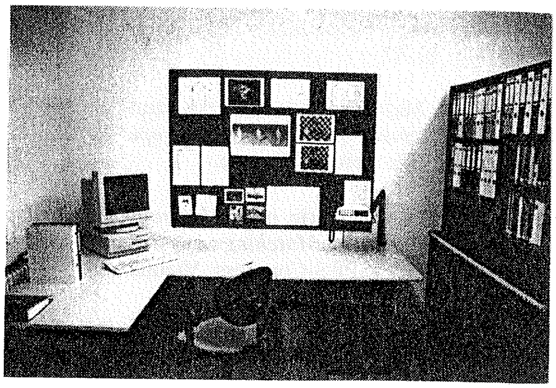

Figure 10.1: *Photograph of a room.*

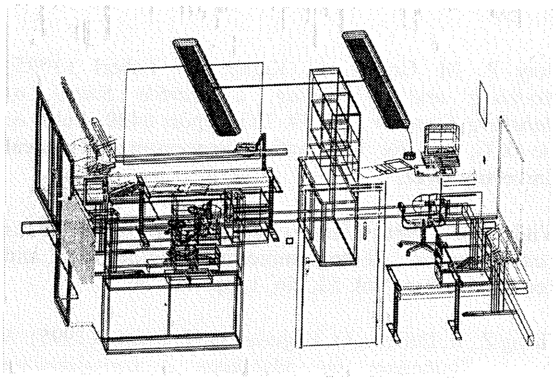

Figure 10.2: *Wire frame rendering of the geometric model of the surface with ~ 60000 elements (from Karner, in print).*

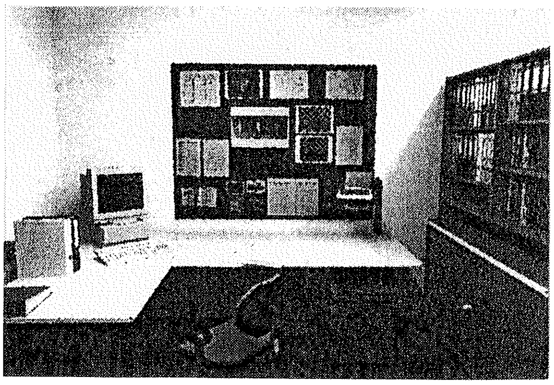

Figure 10.3: *Rendering of the room using surface properties, geometry and illumination via a radiosity model (from Karner, in print).*

11 IMMERSION IN 3-D SCENES

Surfaces are being perceived by a human computer operator when wearing stereo glasses. The object that is being viewed can be interacted with if a 3-dimensional cursor is placed in the field of view. The computer now needs to be able to track the position of the cursor as well as the position of the stereo glasses. As the cursor moves the computer is aware of those motions and can establish a relationship between the virtual 3-dimensional object and the real position of the cursor. In this manner a user can edit a 3-dimensional object interactively. The user can also move freely with the head if the computer can track the position of the head and can change the 3-dimensional object's visualization as a function of the viewer position. In this manner a fully 3-dimensional object could be inspected from the left or the right, from above or below depending on the position of the viewer's eyes.

This is denoted as „immersion“ in 3-d scenes and we are describing an immersive user interface based on a 3-dimensional object surface and the 3-dimensional cursor, accompanied by a tracked viewer. This concept can be a significant element in a chain that goes from sensor sources via point clouds to surfaces and realistic visualizations. The immersive user interface can support the quality control and editing in a fully digital environment at very modest to no additional equipment costs.

12 OUTLOOK AND CONCLUSION

In recent years we have seen a dramatic broadening of the ideas of surface reconstruction. We have described a generalization of these ideas from traditional photogrammetric stereo mapping of topographic surfaces to the use of a whole range of techniques, all aiming at geometric modeling of the surface of terrain or fully 3-dimensional objects. We have also shown a broadening from the traditional measurement of surface points to the more modern integrated view of „digital visual information“, to include the information source in the form of images or raw surface measurements, to combine geometry and radiometry and finally to include the application in the visualization and interaction with 3-dimensional digital surfaces.

The traditional problems of image matching have made slow progress. The human operator is still the best stereo measuring entity. The machine is capable to perform measurements the human cannot take such as ranging, operating with structured light, performing interferometry or doing altimetry. The human can use single image or stereo object reconstruction, not however any of the other techniques. In a trade-off between manual human-based surface reconstruction and automated machine vision the evolution is towards largely automated systems in which the human is merely the quality control and editing agent. This requires that efficient interaction with 3-dimensional data be available in a form that is near a specific application scenario. The geographic information system GIS is in the process of generalizing from 2 to 3 dimensions, e.g. by converting the 2-dimensional multi-layer urban GIS into a CyberCity model. The requirements of planetary mapping, of automated remote sensing, or of industrial inspection all point towards an increased use of automated processes to model the geometry of a surface and to provide tools to also determine non-geometric properties.

We believe that these developments need an integrating view that is capable of fusing various data sources and analysis methods. One obtains a toolbox of procedures so that human interaction is small and limited to improvement of the quality of surfaces.

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