3D SCANNING SOFTWARE: AN INTRODUCTION

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ABSTRACT:

The software tools needed in 3D scanning comprise a large number of modules. Software for scanner control is used to define which parts of an object are scanned at which resolution. Software for treating the huge data volumes of point clouds must allow visualization, data cleaning, filtering, point thinning and registration. If geometrically simple objects are encountered, software is used to fit primitives to the respective points. In the case of more complicated objects as they are frequently encountered in cultural heritage documentation, polygonal meshing is used to replace the surface by a mesh of small triangles. Meshing software must work in true 3D for these tasks and should be flexible enough to adjust to smooth surfaces and edges. Furthermore, it should be possible to map images onto the 3D meshes. A review of presently available software products shows that no ideal software product is available yet.

1. INTRODUCTION

Software for 3D scanning actually comprises several software modules of very different types. Considering the whole process from data collection to final product, a rough distinction may be made as follows:

- Software for scanner control,
- software for point cloud treatment,
- software for fitting of primitives to the point cloud,
- software for the creation of complex surface models,
- software for texture and image mapping,
- software for data and project management.

The quality of these software modules will have a considerable influence on the quality of the final 3D model and on the time needed to achieve this result. Thus, a smoothly performing software product is a basic requirement for the acceptance of 3D scanning.

Whereas the performance of some scanners is really impressive, the software supplied with these instruments is often disappointing. No company has yet a satisfying set of software modules to offer with its hardware. Since some of the modules needed (e. g. for surface modeling) are rather complex, the software development departments of the producers are too small to handle this demanding job. On the other hand, common powerful CAD and 3D modeling software packages are available on the market, lacking the ability to handle the large amounts of points encountered in scanning projects, however. Apart from this, some small companies have decided to produce stand-alone software for the treatment of 3D scanner data. From a commercial point of view, it seems to be superfluous to develop the same modules at many places, considering the relatively small number of copies that can be sold.

Presently, a user looking for fast and high quality data processing is obliged to switch between several software products during data processing. For certain tasks, it may even be necessary to develop own modules. Considering the growing market on one side and the economical constraints on the other, it may be expected that a certain consolidation and concentration may occur in the near future, hopefully leading to better software solutions (and support), thus promoting the acceptance of 3D scanning as a method for 3D modeling.

2. SOFTWARE FOR SCANNER CONTROL

2.1 Scan window and scan resolution

A very simple solution for a fixed scanner without motorized axes would be the use of a fixed window with a pre-set resolution. In this case, the only control element would be a start button, and the only purpose of the scanning software would be the computation of 3D coordinates from the measured elements and the storage of those in a pre-described file and format.

For a more sophisticated approach, especially for instruments with axes, it should be possible to chose from a range of possible resolutions and to select one or more individual scan windows.

The scanning process can be organized much more intelligently, however. Among possible improvements are
- a choice of different possibilities of window definitions (digital input, using the laser beam itself, or using a framing function in a camera image),
- 'moving' windows that can follow long bent structures (e.g. pipes),
- automatic or semi-automatic adjustment of scan resolution for the registration targets detected in object space,

- automatic adjustment of scan resolution in order to achieve (near) constant grid sizes on surfaces at different distances from the scanner, or depending on object definition (low resolution in smooth areas, high resolution at edges).

2.2 On-site visualization and registration

During the scanning process on site it is highly desirable to have reliable information about the progress and the completeness of the scan. Since this matter can get totally out of hand when complex 3D structures with many hidden areas are surveyed, a tool to register several point clouds should be available as well as a point cloud viewer and at least a simple tool to create a rough surface mesh.

The provision of these features on the computer controlling the scanning process is not really a technical problem since they are part of the processing software anyhow. Often, the processing software is needed at the home office for a previous project during a scanning campaign, however. Therefore, the licensing policy should provide those tools on both, the scanning and the office computer, even though only one license is bought.

3. SOFTWARE FOR POINT CLOUD TREATMENT

3.1 Visualization

As a first processing tool, a viewer for the presentation of point clouds should be available, allowing spatial rotation and panning as well as zooming in and out. Since very large numbers of points may have to be handled, the performance of this tool should be optimized which includes point thinning (in the viewer only). Attribute dependent color coding (depending on observation point, distance, or reflectivity values) can support this first interpretation of the data.

This tool, too, should be available without any extra license fee since it is needed in many cases by the clients to have a first possibility to review the scanning results.

3.2 Data cleaning in single point clouds

Since the single point measurements of a scanner are not individually supervised, there are several reasons for possible point recordings that do not represent the selected object surface. Among these are
- reflections from objects in the background,
- reflections originating in the space between scanner and object (trees and other objects in the foreground, moving persons or traffic, atmospheric effects such as dust or rain),
- partial reflection only of the laser spot at edges,
- multiple reflections of the beam,
- range differences originating from systematic range errors caused by different reflectivity of the surface elements,
- erroneous points caused by very bright objects (lights).

Most of these wrong points can be eliminated best before several point clouds are registered. The elimination process has to be done interactively since no automatic method can foresee all possible constellations. Intelligent software features can assist in this process, however, and speed up this annoying editing process.

Points in the fore- and background can easily be eliminated by the introduction of range limits (digitally or with the aid of graphical tools). Wrong points originating from multiple reflections can usually by caught with this method, too.

More difficult to detect are wrong points at edges. Depending on the percentage of the laser spot reflected at the edge, the resulting offset may be large or very small. Since the effect is systematic (e.g. for triangulation scanners the wrong point can always be found on the extension of the beam from scanner to edge, Boehler et. al., 2001), the software should search for such candidates, highlight them, and leave it to the operator to keep or delete them.

Some tests indicate that certain scanners show range deviations depending on the reflectivity of the surface material. It should be examined if these errors can be modeled accurately enough to make an automatic correction process possible.

3.3 Data filtering and point thinning

In addition to the gross errors described in the previous section, the scanning results will show a certain noise due to the limited accuracy of the measured elements. If the object part is known to be smooth, the application of a low pass or median filter can improve the situation considerably. It should be noted, however, that filtering will influence all object parts in the same way. If the object consists of smooth parts as well as of edges, filtering may not be advisable at this point of the process.

Point thinning can have a similar effect as filtering if those points having large deviations from an intermediate surface are preferably deleted. If several scans were taken from different observation stations, it may be advisable to wait with point thinning until all measurements are combined in the registration process (see below, 3.6).

3.4 Registration

Registration is needed for two different purposes:
- Combination of several point clouds taken from different observation points or
- referencing the object in a global coordinate system.

Tie and control points which are recognizable in the point cloud are needed to accomplish this task. These points may just be features of the object (e. g. corners) or special targets (spheres, flat targets with high reflectivity) at carefully chosen locations. In the case of global coordinates, these targets have to be surveyed by geodetic methods (tacheometric polar surveys or sections) or close range photogrammetry (bundle adjustment). In any case, a sufficient number of known points (three, better four) in a point cloud will yield better results than just stitching the clouds together with tie points. On the other hand, if overlap is large enough, many surface points are available to give enough

geometrical strength to a solution using surface conditions only. In any case, it should be considered that error propagation may be unfavorable for long objects and inner or outer closed surfaces consisting of many single scans.

Since objects, conditions and accuracy demands may differ very much from case to case, an ideal registration software should allow both, registration by special targets and by overlapping point clouds (or a combination of both). Rigid least squares adjustment should be available for either task.

3.5 Data cleaning in registered point clouds

Some wrong points may have survived the previous cleaning process (3.2) or can definitively be interpreted as errors after registration only. Those have to be eliminated now, at this stage of the process.

3.6 Point thinning after registration

Due to overlapping areas where points are abundant, but also due to different distances from the scanner and different angles between the laser beam and the surface normal, point density will be differing to a great extent within the object. A good point thinning software should not only consider an even point distribution with respect to the surface, but should also select those points for deletion which have poorer accuracy due to poor incidence angles or due to larger distances from the scanner (which is of special importance in the case triangulation scanners).

Another condition for point thinning is based on the fact that less points are needed on smooth surface regions than in the neighborhood of edges. This condition may be introduced at this stage of the process or – especially in the case of a subsequent creation of a triangular mesh – at a later processing stage.

3.7 Simple plots derived from point clouds

Usually, point clouds are not sufficient as a final documentation result. They might be considered as a means of archiving the geometry of an object, however, much in the same way as photogrammetric images can be archived for later processing. If this is planned, the point cloud data should be evaluated carefully and standards should be demanded, defining if and how the procedures mentioned above (cleaning, filtering, registration, thinning) have to be applied before the data are archived.

If cross-sections are required, those can be derived from the point clouds by selecting a thin layer of points near the plane where the section is needed. The generation of lines connecting the points can be accomplished in 2D if an appropriate tool is supplied with the scanning software or after importing the selected points into a CAD program.

4. SOFTWARE FOR FITTING OF PRIMITIVES

If the scanned object consists of parts of geometric primitives (such as planes, cylinders, cones, spheres, ...) or its geometry shall be reduced to such a simple representation, these primitives must be fitted to the point clouds belonging to the respective object parts. CAD programs, which actually should provide appropriate tools, are presently not able to handle the large numbers of single points supplied by 3D scanners. Possibly, it should not be too difficult for the developers to improve the performance of these software products to the new requirements arising from the 3D scanning techniques.

Fitting software solutions supplied for 3D scans differ considerably as far as performance is concerned. If there is a foreknown collection of primitives (e. g. in the case of an arrangement of pipes with standard diameters in an industrial environment), automatic fitting methods are available which need only little manual input and editing. This applies also to much more complicated structures (such as flanges, pumps, and steel girders) if certain types (only) are known to be present as parts of the whole object. Some software products even supply links to respective 3D CAD catalogues. If primitives with different parameters have to be expected, the software must provide means to manually pre-select those parts of the point cloud which belong to a primitive to be fitted. Since this selection has to be accomplished in three dimensions on a two-dimensional screen, it is important that this task can easily be handled and that it is tolerant against points included erroneously into the pre-selection.

In cultural heritage documentation, primitives are usually not sufficient for the representation of the objects encountered. Classical architecture could be treated this way, but 3D scanning does not really seem to best method for its documentation.

5. SOFTWARE FOR THE CREATION OF COMPLEX SURFACE MODELS

5.1 Polygonal Meshing

2½D versus 3D. Polygonal meshing is a standard method to achieve a geometric description of an irregular surface. The method is well known to surveyors and photogrammetrists from topographic applications. It has to be realized, however, that for topography 2½D solutions are sufficient, i. e. the whole geometry can be described attaching height values (vertical distances from a reference plane) to 2D vertices defined in this plane. This method, included in some 3D scanning software as only meshing alternative, can only be used for modeling 2½D objects such as half reliefs. True 3D polygonal meshing, on the other hand, must be applicable for closed objects, like statues, and allow the modeling of hollow and open object structures (such as the inside and the handle of a jug). Since this is a rather complicated process, it is not surprising that the solutions offered presently leave much to be desired. Computing time can be excessive and the geometry of the results does not always represent the wealth of information contained in the original point cloud.

Point thinning. Point thinning has already been discussed in sections 3.3 and 3.6 of this article. There, the thinning procedure served to eliminate excess points originating from high point density due to overlapping scan areas or short object distances from the scanner. Since these thinning conditions are based on

the scanning geometry (see above), it seems advisable to run this process prior to meshing. Nevertheless, all thinning operation steps can be combined into one procedure executed immediately prior to the mesh triangulation process. It should be noted, however, that the conditions for point thinning in 3D modeling are different: It is economical to leave a dense point pattern near curvatures and edges whereas only few points are needed in smooth areas of the same object. This is contradictory to the algorithms of some 3D meshing programs which demand an even point pattern over the whole object.

Operation and performance. In theory, the whole triangulation process for meshing should run automatically after the user introduces a parameter defining in one way or another the resolution of the 3D object to create. In reality, many software products demand much interaction by the operator, e. g. because of the requirement to define sequentially partial areas of the object where a local 2½D meshing has to be performed. Often, unreasonable triangles are created or holes are left in the mesh although enough points were available in the region.

Edges. If the scan resolution was high enough, the software should detect edges by itself, making sure that points close to edges are not deleted and that the sides of the mesh triangles do not run across an edge. Since edges are not always perfectly defined, the user should have the opportunity to define edges where these conditions have to be enforced.

Editing. Some problems originating from the scanning process (such as wrong points, noisy data, or concealed areas) as well as problems arising from the mesh triangulation (holes, unreasonable triangles) make it necessary to edit the triangular mesh. Procedures to detect problematic areas as well as intelligent editing tools should be provided in order to come to a satisfactory result within a reasonable amount of time.

Expenditure. Several software products are available for 3D polygonal meshing. Their flexibility and performances vary considerably. The generation of an acceptable result (i. e. including editing) may be accomplished in 10% of the time with one product as compared to another one, whereas other products again may not be able to solve the problem at all.

5.2 NURBS

When NURBS modeling of a surface is chosen, the parameters of spline type curves are used to describe the surface instead of discrete mesh points. This can reduce data storage space considerably. Also, when the surface is known to be smooth, the use of NURBS modeling can remove the noise resulting from scanning. NURBS modeling is supplied with some software packages for 3D modeling and even with some packages developed for handling 3D scanner data. It seems to be very useful for relatively small technical parts (e.g. a car fender) but there is a limit presently to the number of points resp. curves it can handle in the case of large, complex objects.

5.3 Texture and image mapping

Texture mapping. It is the texture only that makes any visualization of surfaces possible. The most simple case, a white texture, may give the object an appearance like alabaster. This applies only, however, if one or more light sources are defined for a virtual illumination. Also, the reflectivity properties (relation between direct and diffuse reflection) of the materials have to be defined, which will result in a rougher or glossier surface appearance. More complex textures and more sophisticated illumination procedures may be supplied with the scanning software, Stand-alone 3D modeling software may be used as well - if it can handle the large and complex objects that are common in cultural heritage.

Image mapping from scanner data. Image information may be provided by the scanning process. In the case of ranging scanners, an attribute representing the strength of the returned signal may be available. If normalized (considering the effects of different range and different incident angles), this value can be used to create a gray tone image of the object. The cameras of triangulation scanners can supply a similar information or even record an image of the whole field of view. In most cases, these simple devices do not supply images of the high quality desired for a documentation task, however.

Image mapping from separate cameras. For high image quality, especially for color images, it is advisable to use separate cameras (digital or film) to produce the images for mapping. Camera locations close to the scanner locations facilitate the mapping process. Orientation parameters (location, rotations), approximate values at least, should also be recorded on site. Illumination should be as uniform as possible (which is easy to demand but hard to achieve).

Image projection and mosaicking. The images have to be reprojected onto the object. Although software is available for placing images on the object using identical points "without involving any photogrammetry", the result may be achieved faster (and with a better geometric quality anyhow) if photogrammetric techniques (calibrated cameras, orientation parameters from bundle adjustments) are used. As compared to mosaics for topographic applications, the process for true 3D objects is by far more complicated. This may involve, for example, a new process for every small surface element to decide (based on the incidence angle) from which of the available images the information has to be taken (Visnovcova et. al., 2001). Radiometric corrections regarding brightness, contrast and color balance may also be very difficult to apply since illumination conditions during image acquisition will never meet the pre-condition of being the same on every surface element of the object. There is no need to add, that image mapping is a very troublesome procedure and that there remains a large list of wishes for the software developers to be met (Marbs, 2002). This leads again to the question if the necessary professional and economical resources can be supplied by the scanner producers, by small companies specializing in this field, or by the large software houses involved in CAD and 3D modeling.

6. SOFTWARE FOR DATA AND PROJECT MANAGEMENT

6.1 Data tracking and quality control

Many processing steps may be necessary to come from a set of point clouds and additional data such as surveying results or images to a final 3D representation. During these steps, observations are altered, adjusted, or deleted. Records should be kept documenting all actions applied during the project. Wherever adjustment processes are involved, statistical values, such as standard deviations and residuals, should be supplied. Graphical tools to visualize the differences between the original point cloud and the final model are of special importance for a final quality assessment.

6.2 Data import and export

Scan data. Every processing software should be able to import measurements taken by various scanners. This is an obvious condition for stand-alone software products. If software from scanner manufacturers is used, there might be a demand, too, to use it for other scanners, especially when data from different types of scanners (e. g. providing different resolutions) has to be integrated. The Cartesian coordinates of scanned points are not sufficient as a data interface since they do not contain information about the distance and the direction from where a point was scanned. This information may be important in subsequent operations such as cleaning, thinning, meshing and image mapping (Marbs, 2002).

CAD and 3D modeling software. Since results have to be exported to CAD and 3D modeling software for further processing and/or storage, it is necessary to have export tools available which are suitable for the most common systems. Often, scanning results have to be compared against existing data models. This would also call for appropriate import tools if the comparison is to take place using the scanning software.

7. AVAILABLE SOFTWARE PRODUCTS

As shown above, "3D scanning software" actually means an extensive collection of modules for very different purposes. Some are specific to a certain scanner, some to 3D scanning in general, some are tools that are needed for any kind of 3D modeling. Presently, all producers of 3D scanners (list see Boehler, Marbs, 2002, or WWW, 2002) supply a selection of modules. None can be regarded as complete and satisfactory. Since the demand is obvious and the market is growing, some stand-alone software products for 3D scanning are available, too (table 1).

It seems to be inevitable, however, that a certain consolidation will take place since the market is growing indeed, but not large enough for two dozen of competitors. Large CAD and 3D modeling software houses may also compete in this market if they succeed to upgrade the performance of their products for the import and handling of large numbers of points.

Producer	Type
3D Veritas	3D-Veritas
InnovMetric Software	Polyworks Modeler
INUS Technology	RapidForm 2001
metrologic group	Metrolog II
octocom AG	OctoCAD
Raindrop Geomagic	Geomagic Studio
SDRC	Imageware Surfacer
Z+F UK Ltd	Light Form Modeller

Table 1. Overview of 3D scanning software supplied independent of scanner producers. More software is supplied by scanner producers (see table 1 in Boehler, Marbs, 2002).

8. CONCLUSIONS

As compared to industrial applications, cultural heritage applications of 3D scanning often involve more complex objects. This results in more complex processing which in return makes more complex software products necessary. 3D scanning will become an accepted alternative to other metric recording techniques only, if adequate software is made available in the future. On the other hand, this will result in a 3D documentation quality and comprehensiveness that could not be envisaged a decade ago.

9. REFERENCES

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