OBJECT MODELING BY GEOMETRIC MATCHING FOR A PROSPECTIVE PORTABLE 3D SCANNER

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ABSTRACT

With the evolution of 3D-scanner technology, the combined measurement of color and geometry of objects and scenes becomes feasible within a portable device. It opens new perspectives for the generation of virtual 3D models and applies to domains like multimedia, museography, reverse engineering... Several scanner technologies and object modeling schemes are possible. This paper discusses some of these possibilities and shows why the modeling by geometric matching of object views efficiently assists a universal portable device in the modeling task. It introduces the concept of a global architecture involving a remote portable 3D scanner linked to a powerful modeling facility and presents examples for the expected results.

KEYWORDS

3D scanner, object modeling, multimedia, virtual worlds, portable scanner

1. INTRODUCTION

The increasing use of virtual object representations for multimedia and other applications calls for effective modeling means in order to create such representations out of real objects. Since the manual model construction with a standard modeler is a quite tedious task, 3D surface digitizers and modeling tools get used more and more for this purpose.

A wide variety of scanning principles is available. Laser scanners typically use the principle of triangulation between a laser beam and an imaging camera to provide a range profile or range image. Structured light scanners use the triangulation principle between some projected light pattern and an imaging camera. Autofocus scanners derive the depth from the focused image distances. Other principles apply [1].

3D scanners give direct access to the 3D geometric information of object surfaces, usually in the form of a range image. They allow an accurate digitizing of an object surface.

The trend in scanner technology is towards fast and cost effective devices. It naturally leads to the development of prospective portable devices, which however, because of the way they are used, require a data processing that differs from the one used in most static devices.

Data processing is required for the purpose of object modeling. In fact, simple scanning is not sufficient because, as 3D objects self occlude, one acquisition captures only a subpart of the entire object surface. Object modeling thus involves the measurement of several views of the object and their combination into one unique object representation.

This view combination is straightforward if, during digitizing, the object is moved in a well known coordinate system like for instance a rotation table: the relative pose of successive acquisition configurations is known. This case is typical for the static scanners. It usually implies the presence of an accurate positioning system used to measure the pose changes of the object or the scanner.

Different positioning principles can be used for this purpose. Some, like the mechanical positioning systems, directly measure the object or scanner movements between the consecutive scans. Other systems, like the photogrammetric methods, derive the movements from correspondences of same landmarks found in the scanned images.

Additional positioning systems should be avoided in the case of simple portable device. Also the additional work of actively applying stickers on the object for the landmarks should also be avoided. A view combination method that gets rid of these requirements is needed.

With the geometric matching approach [5] a solution is provided that allows to model objects by view combination without any need for a priori positioning information. The principle is to register views based

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on the sole features of the successive view geometries.

The purpose of this paper is to show that this geometric matching approach is a privileged method for efficiently assisting a universal portable device in the modeling task. First, it discusses the features and requirements of a portable 3D scanner for the purpose of object modeling. Then, it exposes the reasons why additional positioning system should be avoided. Finally, it presents and discusses the possibilities and also the limits of a geometric matching approach used for the purpose of view combination.

2. PROSPECTIVE PORTABLE 3D SCANNER PRINCIPLES

Prospective portable 3D scanners may rely on one of the following scanning principles.

2.1 Silhouette scanners

Silhouette scanners [2] make use of a simple imaging camera that is used to record several views of the object of interest. Each image is calibrated by means of a reference object that must be present in the scene, like a calibrated reference circle. The reconstruction involves silhouette extraction in each view and reconstruction of the object by volumetric removal of the silhouette external part.

Simplicity is an advantage. Limitation to silhouette separable shapes and the requirement of a reference object are disadvantages.

2.2 Stereo scanners

Stereo scanners use the triangulation from two or more imaging devices to compute the depth.

The use of simple imaging devices is an advantage. Poor performance in featureless scenes is the disadvantage.

2.3 Range scanners

Most of these systems can be classified according to one of the following techniques:

Active triangulation: Light spots or lines are projected on the object and observed through a calibrated camera under a different view angle. The projected light is detected in the camera image and the depth is calculated by triangulation.

Focus/defocus: Depth from focus is calculated from the lens configuration corresponding to the best object focus. Depth from defocus is obtained from the optical camera and lenses parameters combined with an image blur measure.

Time of flight: A laser beam is pointed at the object and depth is obtained from time of flight or from phase shift measurements.

The mentioned scanner principles differ in features and advantages. Very generally, the choice may differ from application to application but all are candidate for portable scanners.

Range scanners do however not present the disadvantages of the two scanner classes mentioned above and will therefore be considered hereafter and for the rest of the paper.

3. OBJECT MODELING

We thus have the concept of a global architecture involving a remote portable 3D scanner linked to a powerful modeling facility.

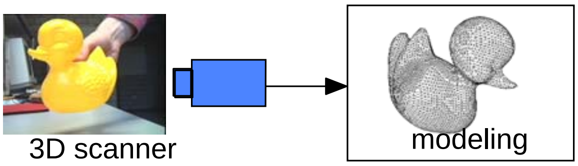

Fig. 1 3D portable scanner with a remote modeling facility

With the range data available from such portable 3D scanners, the modeling of a full 3D object obviously consists of some operation in which several different views of the objet must be combined to form a complete description of the object.

Two steps are required. A view-positioning step and a later view fusion step.

3.1 View positioning

View positioning methods are typically:

- Fixed object and continuous measurement of the scanner pose as it is moved around the object.
- Fixed scanner and continuous measurement of the object pose as it is moved, i.e. on a turn-table or a translation table
- Bringing onto the object landmarks that are later used to register the views.
- Projection of fixed landmarks onto the object
- Using the geometry of the object to register the various views

Most methods suffer from some limitation in the universal use of the scanner: use of additional measuring devices or modification of the scene. Only the last method relies uniquely on the pure range data delivered by the range scanner. It will be developed further in Section 4.

3.2 View fusion

Several methods exist for integrating registered surfaces acquired from different views. They differ mainly in how they treat the redundant overlapping zone of the two registered surfaces and can be separated into two groups: partial erosion and complete retriangulation of the surface points.

Methods using a partial erosion approach erode the overlapping surfaces until the overlap disappears. The two triangle meshes are then recombined at their frontiers in order to have one unique mesh for the union of the two surfaces. Other authors discard the mesh information from the triangulated views if calculated at all and retriangulate the overlapping zone or even the complete point set. See [4] for a discussion of references.

4. MODELING BY GEOMETRIC MATCHING

Modeling an object requires basically to successively adding a new view to the virtual model under construction. First the view is registered to the model and then the respective meshes are fused together.

4.1 View registration

As mentioned under 3.1, the problem is to register the various views relying only on the measured geometry of the object surfaces. It is assumed that the views have some overlap such that these descriptions of a common part can be used for view registration. View registration is performed by geometric matching.

To perform this task, Besl proposed a surface registration algorithm called ICP [3]. This geometric matching algorithm registers two surfaces by iteratively moving one surface with respect to the other until a global measure of the intersurface distance is minimized. As an example of the application of ICP to view registration, figure 1 illustrates the registration of two different range images of a duck acquired under viewing angles differing by about 15°.

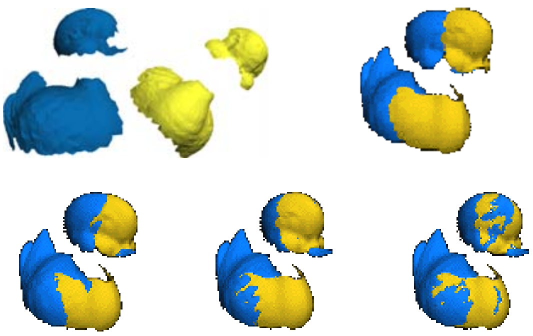

Fig. 2 View registration by geometric matching

4.2 Mesh fusion

Since the object views can be easily triangulated using the range image structure, the partial erosion approach already described under 3.2 is preferred. It can in fact be used in a very attractive and efficient way when combined with the ICP algorithm, because it benefits from the closest point relationships established during the geometric matching. Once the matching is established, each point of one surface has its neighbor in the second surface, a fact that can be used to remove unnecessary points of this surface and to fuse the surfaces together exactly at the points where the second surface ends. There is no need to run an extra task to erode overlapping surfaces.

Once eroded, the one surface is fused to the other by linking their frontiers. Running an iterative procedure that fills the gap with triangles links the points of each frontier. Figure 3 illustrates how the frontiers between surface X and surface P are linked. From a first link established between X and P and shown left, the procedure proceeds iteratively by filling the gap, choosing at each step to grow with the triangle of minimal surface as shown right.

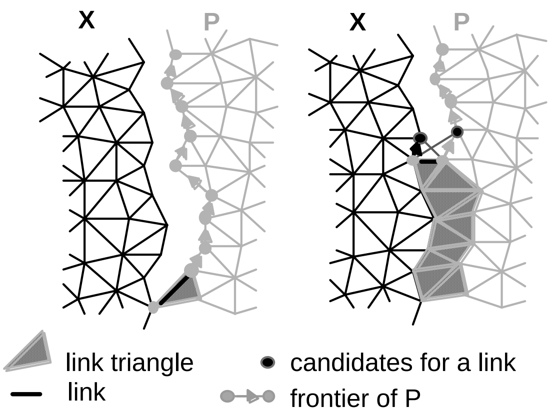

Fig. 3 Surface fusion at the frontier of X and P

4.3 Iterated view registration

The modeling starts by matching two single views that are then fused. This result represents the first form of the model. At each new iteration, an additional view is considered, then matched to the model under construction and finally fused to it. The model construction continues until exhaustion of views.

The described modeling performs successfully as shown later in Section 5.

At the actual level of development, view registration is performed interactively. An important question remains open, asking whether the modeling can be fully automated. The next paragraphs discuss some aspect of this automatic operation.

4.4 Registration convergence

The performance of the ICP algorithm to successfully match two surfaces depends on the choice of a *good* initial pose of the two surfaces [6]. If the ICP algorithm is guarantied to converge with any initial configuration, not all configurations will converge to a successful match. A quantitative view of the convergence behavior is provided by SIC-maps like the one shown in figure 4. This map displays (in black) the SIC-range, i.e. the part of the initial configuration space that leads to successful matching. The relative high percentage of black of this particular SIC-map speaks for a rather large SIC-range of this particular object.

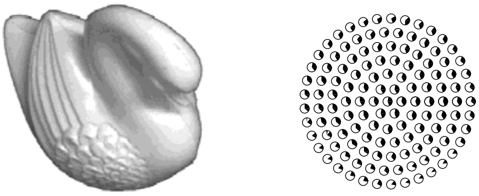

Fig. 4. SIC-map for the 3D-object "swan"

4.5 Need for initial pose estimate

From above, it is clear that applying ICP to register surfaces is successful only if the initial configuration is a *good* pose, i.e. if it belongs to the SIC-range. The general case where absolutely no knowledge is available about such a good pose requires searching the configuration space, which is 6-dimensional. Therefore, general full automatic registration involves testing a very large number of initial configurations.

The process can be speed up by several means as for instance using a priori information. A simple measuring device for position and/or orientation could provide such positioning information. No precise measurement is required and rough pose estimate is sufficient to start a successful surface-matching algorithm.

A further possibility to obtain a good initial configuration is an initial match based on pertinent features. Using color, it is possible to significantly improve the range of successful convergence of the registration and therefore speed up the overall registration. This is clearly demonstrated in a comparison where matching of surface patches is performed based on geometry alone, color alone, or geometry and color [8]. Notice that the use of a feature like color also permits to get rid of special cases, like when the geometry is ambiguous and does not determine a unique registration.

Other features providing potential for finding an initial pose estimate are numerous and include orientation [8], curvature and spin-images [9]. Full and efficient exploitation of such features for initial pose estimation offers good perspectives towards a full automatic modeling from single range views.

5. RESULTS

Two examples are presented to illustrate the effectiveness of this modeling. Figure 5 shows the 3D model of the duck reconstructed from 10 single range images and figure 6 illustrates the fact that the modeling by geometric matching extends in a direct way to the processing of colored range images if the scanner provides such information.

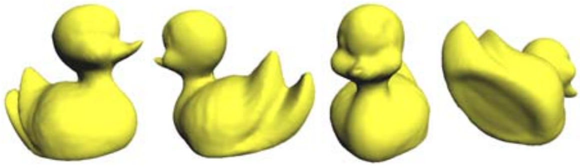

Fig. 5. Model reconstructed from range images

Fig. 6. Color model reconstructed from range images

6. CONCLUSIONS

An object modeling facility based on geometric matching methods is a good candidate for assisting a universal portable device equipped with a range scanner. The presented analysis of the modeling by geometric matching and view fusion suggests that such a modeling facility should be made available to the user of such scanners. It also shows that the way towards full automatic modeling requires an intial pose estimate that can be provided either by a cost effective but relatively inaccurate positioning device or additional computational effort based on feature matching.

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