Toolkit for registration and evaluation for 3D laser scanner acquisition

Rémi Synave
UMR 5800, Laboratoire Bordelais de Recherche en Informatique
Université Bordeaux 1, France
synave@labri.fr

Pascal Desbarats
UMR 5800, Laboratoire Bordelais de Recherche en Informatique
Université Bordeaux 1, France
desbarats@labri.fr

Stefka Gueorguieva
UMR 5800, Laboratoire Bordelais de Recherche en Informatique
Université Bordeaux 1, France
stefka@labri.fr

Abstract

The construction of numerical representation of 3D objects based on laser scan acquisition is composed by three steps : the range image acquisition, the registration and the integration. Experiments show that registration plays a key role in the final representation precision. This article is a practical report containing the description of a toolkit for registration and for evaluation of the registered mesh model according to geometrical and topological criteria. Examples of manipulation of the toolkit are provided for synthetic and real objects.

1 INTRODUCTION

The reconstruction of a complete model with a laser scanner consists in three basic steps : the acquisition, the registration and the integration [Rus02, Pau05, Ber02, Jae03, Dor98]. Data acquisition involves obtaining depth data of an object from multiple viewpoints. During registration, transformations that relate the views are determined to bring the object regions shared between them into alignment. Integration merges data from multiple views such that a single surface representation is created in a unique coordinate frame.

Several software packages to register and/or to integrate range images are available. For example "Polygon Editing Tool" [POLYG] supports the entire reconstruction pipeline from the acquisition to the integration. During the volume integration step, three modes are enabled : smooth, precise or in-between. The smooth integration mode produces an even and regular object boundary surface but fine shape features and details are lost. In the precise mode, surface features are preserved but the resulting shape tends to invalid fragmentation. In order to determine the proper extent of smoothing one should proceed to a great number of experimentations. Unfortunately, the conclusive representation quality is operator dependant. An other example of reconstruction software package is "VRMesh" [VRMESH]. The distinctive characteristic of this software is the broad range of supported data exchange formats. This is particularly useful in the case of heterogeneous reconstruction pipeline when the different reconstruction steps are performed on different hardwares and thus necessitating numerous data conversions. "EgSolutions" [EGSOL] is a software suite that provides both a stand alone software and an API for model reconstruction and mesh model evaluation.

All these softwares are not open source and no information is available on the algorithms in use during the different stages of the reconstruction. That is why the evaluation of the reconstruction is difficult to achieve.

Our objective is to elaborate a software suite for the complete reconstruction process in such a way that the final reconstruction precision is under control. The main purpose of the present article is to give a practical report and to enlighten the registration step with respect to the related range image transformations and data interactions. First a model package is proposed to handle the set of data structures and the underlying model operations essential for both the range image storage and the data exchange flow during the reconstruction. Next, a package for the automated ICP (Iterative Closest Point) registration is put forward. Finally, a mesh evaluation package is elaborated in order to assess the quality of the registered range images. The presented toolkit is the building block for a further reconstruction coverall.

2 SOFTWARE TOOLKIT PRESENTATION

The developed software toolkit as illustrated in Fig.1 is compound of three packages : the model package contains the data structures and the basic function implementation for mesh model manipulation, the registration package supports the range image registration and finally the evaluation package includes functions

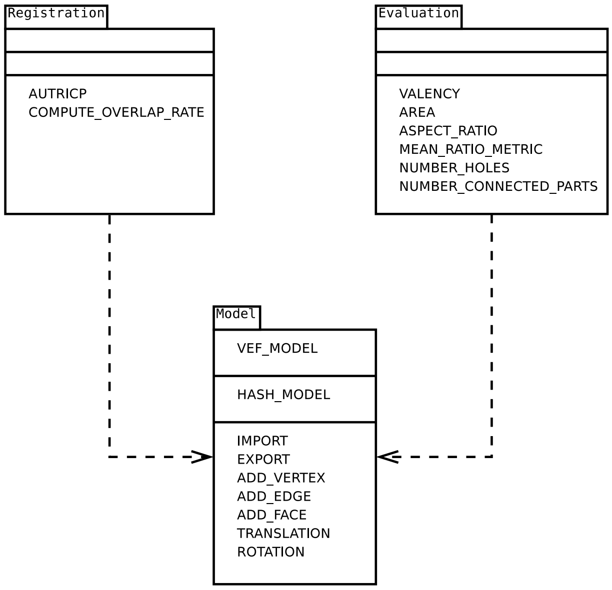


Figure 1: Package diagram

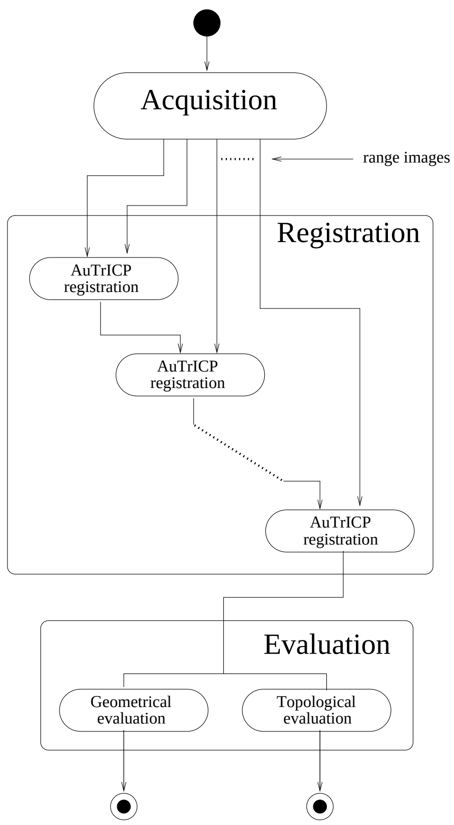


Figure 2: Interaction Overview Diagram

for topological and geometrical mesh model evaluation. The dashed line arrows in Fig.1 reflect the package dependencies.

2.1 Model Package

Two data structures have been implemented in order to stock the data range images.
The first one, called “vef_model”, is composed by the set of vertices, edges and faces. Each edge is defined as a couple of its boundary vertices and each face as a triplet of its boundary edges. This representation is an evaluated one as long as the object boundary is explicitly defined. Moreover, topological characteristics as mesh element neighbourhoods can be extracted in a constant time. The second data structure, “hash_model” is inspired from [War04]. This data structure is composed just by the set of vertices and the set of faces. Each face is defined as a triplet of its boundary vertices. In this data structure, the edges are not explicitly stocked but can be recovered through a hashtable processing. The “hash_model” is compact in memory but is less efficient for algorithms exploiting mesh traversal requests. Supporting the “vef_model” and the “hash_model” data structures permits to optimise algorithm performance according to both speed and memory requirements.
Depending on the acquisition pipeline, at different stage of the reconstruction, different data formats are manipulated. In order to be compatible with most existing reconstruction software packages, converters to five standard formats are provided : OFF, PLY, PGN, VRML and OBJ.
To achieve a reliable and efficient import and export of the “vef_model” data structure, a file format called vef is also developed.
In addition to the converter functions, complementary functions are provided as the model transformation operations and the model element manipulations. The model package ensures the data interface for the registration and the mesh model evaluation.

2.2 Registration Package

According to our experience, the range image registration is a point at which the data reconstruction flow is particularly prone to errors because of noise and miscalibration. Indeed, during acquisition distinct object views (called also "scans") are saved into distinct range images. In Fig.2, the interaction overview diagram in the implemented pipeline is illustrated. Each solid line arrow corresponds to a range image. Between the acquisition and the registration arrows encode initial scan data and between the registration and the evaluation, arrows represent the registered range images. A 3D scan matching is used in order to obtain an optimal alignment. It comprises an identification of the scan matching features [Jos02], a point-correspondences in shared features, and an optimal alignment transformation that put the scans into a shared coordinate frame. In general, neighbouring scans are aligned in a pairwise manner as illustrated in Fig.2. The most popular algorithm of pairwise registration is the ICP [Bes92, Rus01, San04, Yan05]. The major drawback of this method is its restriction to sub-parts registration that makes it unappropriated for our application since we deal with overlapping range images as shown in Fig.3. For this example, each grey scale region corresponds to a human femur scan acquisition. To register this type of meshes, Turk [Tur94], and later Chetverikov [Che02], introduce the TrICP (Trimmed Iterative Closest Point). The TrICP method adjusts the ICP with only the points included in the overlap. No geometric interpretation could be associated to the proposed overlapping rate calculation that makes it not intuitive and not easily worked out.

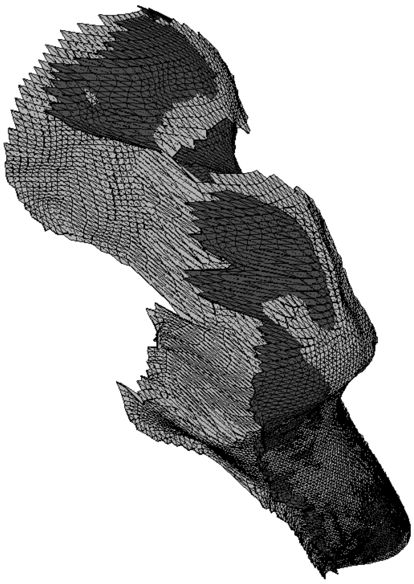


Figure 3: Overlapping of two neighbour range images

In order to avoid this drawback we develop a TrICP variant called AuTrICP (Automated Trimmed Iterative Closest Point) [Syn07]. Our method computes the overlapping rate using the intersection of geometric bounding containers. Each container surrounds an overlapping feature. Different shaped bounding containers like AABB (Aligned Axis Bounding Box), OBB (Oriented Bounding Box) or BS (Bounding Sphere) [Rit90, Klo98, Sur99] are used to establish an optimal match with the overlapping feature shape. The rate of the bounding container intersection defines the rate of the overlapping. The method is totally automatic and produces a well behavioured convergence of the registration.

2.3 Evaluation Package

The libraries in the evaluation package permit to evaluate geometrically and topologically the registered mesh model. An overview of mesh evaluation criteria could be found in [Fre99]. The evaluation criteria we exploit are commonly used in quality mesh evaluation.

The first geometrical criterion is the valency of each vertex in the mesh. Registered range images are represented as triangular meshes. The goal is to produce regular triangular meshes with interior vertices of valency six, and boundary vertices of valency four, with as few as possible extraordinary vertices. Indeed, extraordinary vertices give rise to artifacts in the surface as creases and ripples [Sab02]. An example of a synthetic object mesh model with extraordinary vertices[1] is illustrated in Fig.4.

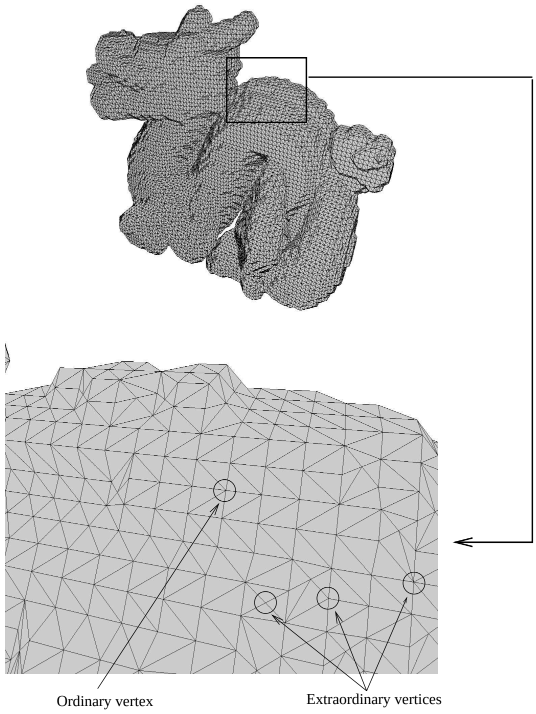


Figure 4: Illustration of ordinary and extraordinary vertices

Further, as one can see also in Fig.4, the triangle shapes could vary in local neighbourhoods and in different proportions. This induces singular mesh elements, corners and cusps. Thus a second criterion, the aspect ratio allows to control the triangle size and shape variation. By analogy, the triangle areas and the mean ratio metric [Mun04] provide an indicator for a harmoniously shaped mesh. Similarly the average and the standard deviation of these criteria are evaluated to deduce an indication of the homogeneity of the mesh.

[1] imported from http://graphics.stanford.edu/data/3Dscanrep/

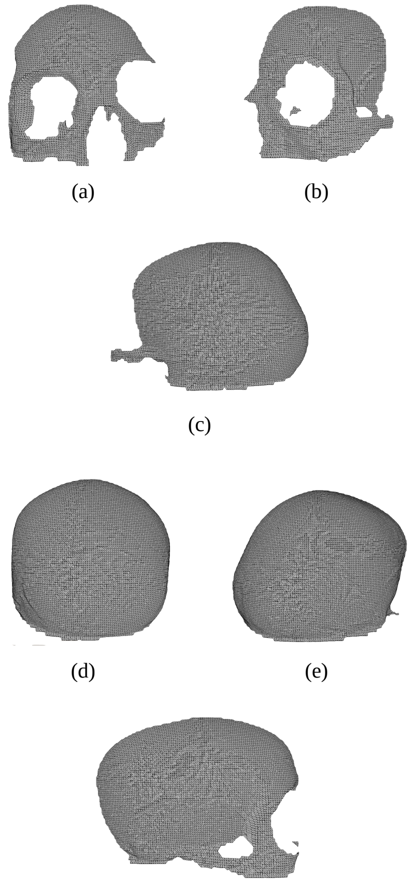
Two topological criteria are used to evaluate the mesh models : the numbers of borders and the number of connected components. Each border corresponds to a hole in the surface and necessitates a careful post-processing. In some case the surfaces are repaired and the holes are blended as long as these borders are due to artifacts. In other cases, each border defines the boundary of a cavity traversing the object. The border is preserved attending for the calculation of the surface characteristics as genus, orientability and compactness. In currently available softwares as Geomagic software (provided by Minolta systems), hole filling and automatic remeshing are operated to repair and to smooth the final mesh model. This process affects the model as a whole and introduces errors in the range image reconstruction. Our aim is to provide tools to work locally on chosen model parts in order to eliminate redundant data and/or filling gaps being as faithful as possible to the initial acquisition.

3 EXAMPLES

The acquisition and registration pipeline on examples of real and synthetic objects are illustrated. Two examples of acquisition, registration and evaluation of real objects are supplied : a human skull and a human sacrum.
An example of synthetic object, a Chinese dragon figurine, is reported.
A simple OpenGl interface has been elaborated to visualise the intermediate stages and the final result.
The first step of the pipeline is the laser scanner acquisition of the separate views. In Fig.5, the human skull acquisition is illustrated. Each distinct image corresponds to a view of the object being rotated on different angles along the scanner axis.

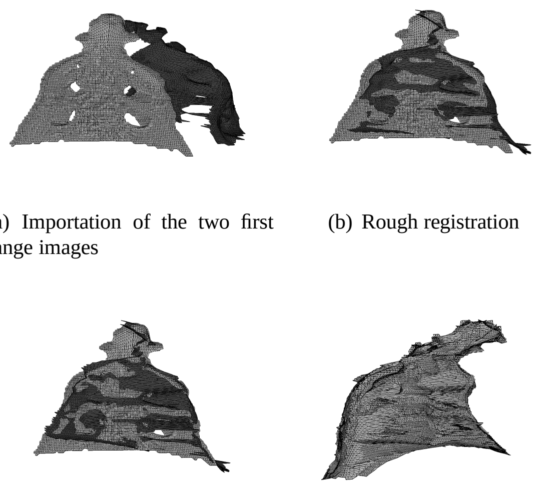
The second step is the pairwise registration between neighbouring scans. We start with the import in the model package of two neighbour scans. In Fig.6(a), these scans correspond to two views of a human sacrum, the initial position view and the sixty degree rotated position view. Next a rough registration is performed as shown in Fig.6(b). During this registration, the two neighbouring scans are matched manually. Further the AuTrICP is applied for a finer registration given in Fig.6(c). The pairwise registration is iterated with the produced mesh and the following neighbouring scans. The final result is obtained when all the range images are processed as shown in Fig.6(d).

The proposed pipeline processing on a synthetic object example[2] is shown in Fig.7. The mesh model is subdivided manually into two parts given in Fig.7(a) and Fig.7(b). Then the initial rough registration is performed as illustrated in Fig.7(c). The final registered mesh model is shown in Fig.7(d)



(a) (b) (c) (d) (e) (f)

Figure 5: Acquisition of different range images



(a) Importation of the two first range images

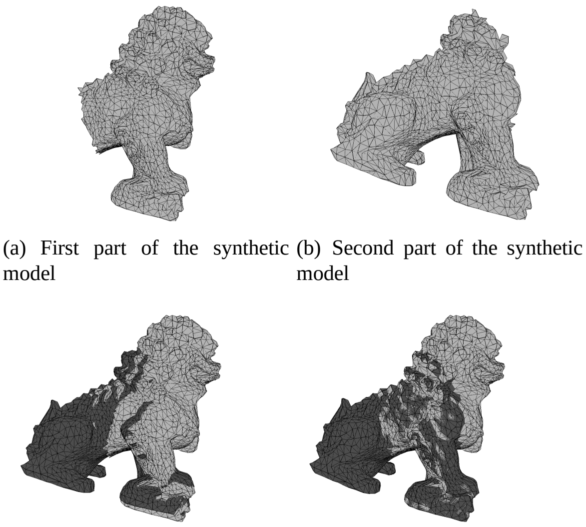
(b) Rough registration

(c) Registration with AuTrICP of the two first range images

(d) Registration of all of the range images

Figure 6: Registration of range images

[2] imported from http://shapes.aim-at-shape.net/index.php



(a) First part of the synthetic model (b) Second part of the synthetic model

(c) Rough registration (d) AuTrICP registration

Figure 7: Registration on a synthetic model

4 RESULTS AND DISCUSSION

The toolkit package data flow is detailed below. First, acquisition and individual scans are processed on an AMD Athlon xp/ 2 GHz/ 1Go RAM and next exported in an OBJ format. Our experimental acquisition platform is a non-contact 3D digitizer VIVID 300/VI-300. Further, mesh models are imported in the model package and "hash_model" and "vef_model" are constructed. The proposed software toolkit operates on an Intel Pentium 4/ 3 GHz/ 1Go RAM. The execution times (in seconds) for the sacrum mesh construction are provided in Table 1. As one can see the construction of the "vef_model" is more time consuming as long as the complete geometry and topology information is saved explicitly. This cost is justified with a low processing time for the query request operations, the border and the connected component calculation, as illustrated in Table 2. The VRML and PGN formats are useful when synthetic object models are imported in the pipeline in order to be evaluated. The last VEF format is specific to the proposed toolkit.

	"hash_model"	"vef_model"
OBJ	0.18	63.41
VRML	0.26	64.27
PGN	0.18	63.32
VEF	0.23	0.26

Table 1: Execution time for sacrum mesh model construction

The registered model evaluation for the sacrum example is given in Table 3 and Table 4. The first column of both figures gives the correspondence between different range images.
The following notations are used for the average and

	"hash_model"	"vef_model"
NmbH	0.23s	0.07s
NmbCC	0.31s	0.02s

Table 2: Execution time for sacrum mesh model topological evaluation

standard deviation of the vertex valency, M_{Val} and St_{Val}, the triangle aspect ratio, M_{TaR} and St_{TaR}, and the triangle area, M_{TrA} and St_{TrA}. The Mean Ratio Metric is denoted as *MrM*, the number of holes are *NmbH* and the number of connected components are *NmbCC*.
As it seen in Table 3, the vertex valency for all scans is stable and tends to the regular vertex valency.
For a harmonious mesh, the triangle aspect ratio is $\sqrt{3}$. Results show that the mesh models should be improved with respect to this criterion. Furthermore, triangle area variation is insignificant that means the triangle size is almost constant. It could be concluded that the geometry mesh quality is satisfactory.

	M_{Val}	St_{Val}	M_{TaR}	St_{TaR}	M_{TrA}	St_{TrA}	*MrM*
1	5.83	0.58	2.71	1.64	1.07	0.73	0.74
2	5.78	0.65	3.15	2.39	1.34	1.14	0.70
3	5.83	0.57	2.67	1.52	1.07	0.79	0.74
4	5.84	0.54	2.48	1.15	0.88	0.52	0.77
5	5.83	0.57	3.07	2.4	1.08	0.95	0.72
6	5.82	0.57	3.25	2.6	1.27	1.01	0.69
7	5.83	0.58	2.86	1.99	1.10	0.87	0.73

Table 3: Sacrum mesh model geometrical evaluation

	Scan	*NmbH*	*NmbCC*
1	0	7	1
2	60	3	1
3	120	2	1
4	180	7	1
5	240	1	1
6	300	1	1
7	complete	21	6

Table 4: Sacrum mesh model topological evaluation

Following the Table 4, it could be seen that the implemented AuTrICP registration method does not distort the initial range image topology structure.

5 CONCLUSION AND PERSPECTIVE

The presented work is a paractical report that describes a set of libraries for the range image reconstruction pipeline, starting with the acquisition of different range images, performing the registration of the complete set of individual scans, and finally, evaluating the quality of the reconstructed range image according to both geometrical and topological criteria. In addition, the software toolkit provides various range data exchange formats. This makes possible the support of heterogeneous acquisition pipeline when different pipeline steps are performed on separate hardware devices. Current research is directed towards implementation of the global relaxation during registration [Pul99]. In this way we hope to improve the robustness of the registration to data acquisition. The volume integration step is also investigated so as to complete the reconstruction pipeline. Moreover, the quantification of the object reconstruction precision needs a deeper understanding. In the future, we want to build and maintain the libraries with the autotools and make available this toolkit as an open source package.

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