Second African Conference on Computational Mechanics - An International Conference - AfriCOMP11
January 5 - 8, 2011, Cape Town, South Africa
A.G. Malan, P. Nithiarasu and B.D. Reddy (Eds.)

Automatic Selective Feature Retention in Patient Specific Elastic Surface Registration

G.J. Jansen van Rensburg*, S. Kok*
*Advcanced Mathematical Modelling, CSIR Modelling and Digital Science, Pretoria ,South Africa, jjvrensburg@csir.co.za

SUMMARY

The accuracy with which a recent elastic surface registration algorithm deforms the complex geometry of a skull is examined. This algorithm is then coupled to a line based algorithm as is frequently used in patient specific feature registration. This addition allows registering target features that are allowed while dissimilar features in a statistical set of geometries can be automatically ignored during the surface registration process.

Key Words: Registration, Patient Specific, Mesh Deformation, Geometrical Modelling

1 INTRODUCTION

In recent years, accurately modelling biomechanics through the application of numerical tools to a patient specific computational domain has seen significant improvement. In many cases it is possible to devote much of the analyst's time to building a single generic model that could describe field values and variation after application of Computational Fluid Dynamics or from implementing the Finite Element Method to within a required accuracy. This generic model can then simply be deformed to closely resemble that of a specific subject within the same statistical sample. To deform a base surface or volume into that of a target configuration, elastic registration is often applied.

Deforming the same surface or volume mesh into that resembling different subjects not only requires far less input from the analyst but has the added advantage of enabling the computation of statistically significant modes of variation within a large enough sample. Principal component analyses can be done not only on shape and form but can also give valuable insight into the principal modes of variation of field values due to a variation in computational domain shape and form.

2 ENHANCED SURFACE REGISTRATION

To demonstrate and motivate the implementation and modification of existing registration procedures [1,2,3,6], attention is given to handling patient specific skull geometries extracted form Computed Tomography (CT) scans. Where complex closely similar geometries need registering, problems would occur for instances where there is a difference in the topology as is typically the case when skull geometries are considered. These differences in topology can arise from the geometry itself, such as a missing tooth or bullet wound in one skull with no equivalent trauma on the other, or as a result of post-processing when surface representations are constructed using voxel data. This means that a requirement to completely register a reference skull onto the target geometry would almost certainly develop the need to alter the connectivity of the reference mesh, destroying one-to-one correlation between all registered geometries in the sample.

It would be undesireable and naive to somehow come up with the difference between or change in skull geometry and then ascribing statistical relevance to the presence of teeth, location of a crack or hole due to decay, a broken zygomatic arch, wound caused by some kind of trauma and even angle of the cut made during an autopsy unless it is the reason for the comparison. Aimed at only matching features relevant to a study also reduces the complexity of the procedure required to match closely related geometries like the human skull tremendously. To overcome this typical problem, a routine is proposed that requires the match of only selected features within an unstructured triangulted surface mesh and a tetrahedral volume representation:

- Geometrically similar features are extracted and represented as ridge and valley lines. From their definition in differential geometry, these lines follow the salient lines on a geometry [4,5,6]. They mainly emphasize structures that are widely used by doctors as anatomical landmarks. In addition, the lines on curvatures that would be singlular to a specific geometry in a sample would also be extracted if such a feature exists.

- The feature lines can be compared to assertain like features between the generic geometry and that of the target configuration. Non-rigid registration is firstly apllied and then a deformation field can be determined from one to the other [6]. The lines are deformed to their target configurations [3,6] while the rest of the geometry is deformed using radial basis function interpolation.

- Feature lines that have no equivalents in either the base or target meshes need to be ignored during registration. From unmatched feature lines the surrounding surface is extracted as part of the surface that should not influence registration and subsequent deformation. Like features on the other hand are also extended to encompass feature surfaces. Feature surfaces are given higher priority depending on the relative calculated curvature between features. The remainder of the geometry is classified as smooth surface and forms part of additional allowable surface for registration.

- Elastic surface registration ensues based on a closest distance to target procedure [1]. The closest triangle to both points in the base and target are determined on the opposite mesh. If the triangle falls within the allowable surface for registration, an orthogonal projection is then made to this triangle's plane to check if this projection lies within the triangle. The displacement required to reach the opposite surface is set to this point or the closest allowable vertex on the mesh if the projection lies outside the triange. The actual deformation for the current iteration is then determined for all of the base nodes from a combination of the required base to target and target to base distances. A smooth displacement field is achieved using Gaussian radial basis functions and smoothing parameters, occationally also applying a few iterations of global mesh smoothing to maintain element quality.

- At convergence of elastic surface registration, the actual base to target surface nodal displacement is known. A diffusion based volume mesh deformation strategy is then used by solving decoupled three-dimensional Laplace equations [1]. The deformed generic volume mesh is obtained.

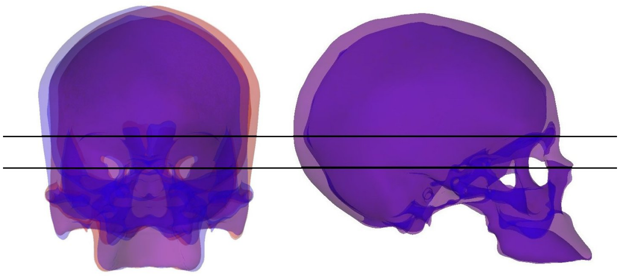
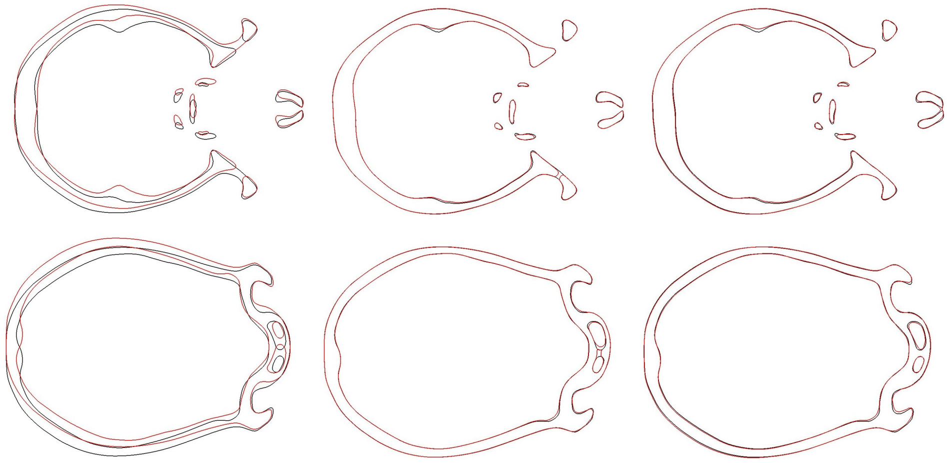


Figure 1: Base (red) and target (blue) surfaces for symmetric geometry estimation. The lines drawn correspond to the contour lines showed in Figure 2.



(a) (b) (c)

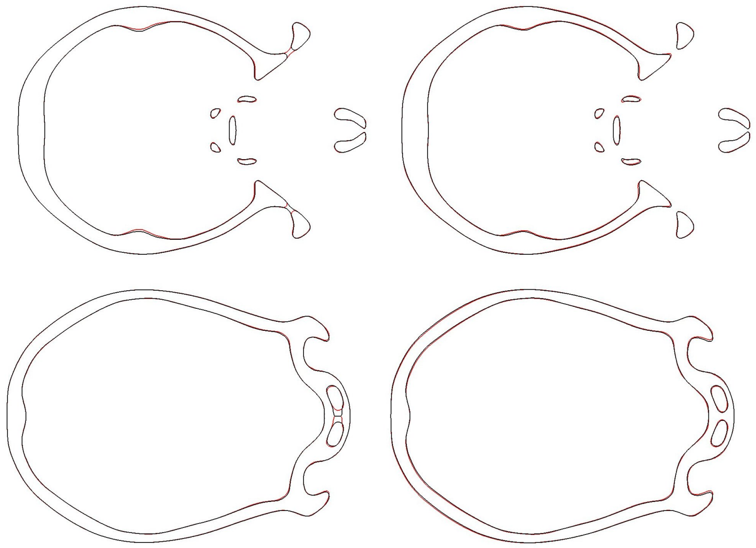
Figure 2: Contours of mesh registration from base to mirrored target at the lines showed in Figure 1. a) Base and mirrored target contours, b) results of original registration procedure, c) results of imposing higher feature priority. For each image the target contour is showed in black.

2.1 Symmetry in skull geometry

As an illustrative example, the task of creating a symmetric version of a specific skull geometry is illustrated using the original surface registration algorithm used in a recent publication [1] along with the results of the modified algorithm giving higher priority for feature to feature registration. To generate a symmetric skull, non-rigid regitration is first performed on a skull and it's mirrored version so that features line up in a least squares sense. Elastic surface registration then gives the deformation required to represent the mirrored surface. Simply taking the average between original and deformed nodal coordinates should then give a symmetric version of the skull geometry. In Figure 1, the base and it's mirrored target for registration surface is seen in red and blue with section contours of registration in Figures 2. The same contours of the resulting symmetric skull is visible in Figure 3. These specific sections of the target and deformed surfaces show clear improvement over the results obtained from the original algorithm.

3 CONCLUSIONS

Many elastic surface registration algorithms exist that achieve acceptable results for applications where simple geometries are addressed. However, these algorithms seem to fail if the geometry



(a) (b)

Figure 3: The resultant symmetric mesh and it's mirrored image for a) the original algorithm and b) proposed algorithm.

is too complex. In combining line based algorithms with a surface algorithm, also expanding the influence of lines and feature surfaces during registration, greater accuracy is obtained in deforming the complex internal features of a skull geometry for example. An intelligent mesh morphing strategy where dissimilar feature surfaces can be extracted automatically also greatly reduces the amount of user input required.

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