# Multiple Geodesic Distance Based Registration of Surfaces Applied to Facial Expression Data

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*Abstract*— **In this paper we propose a method for registration of surface shapes. In particular, we are concerned with facial shape under variation of facial expression. The registration is controlled by few manually identified landmarks and based on matching the shapes in spaces spanned by the geodesic distance to triplets of such landmarks. In a final step a robust mean operator is usied to arrive at the final registration.**

## I. INTRODUCTION

With the advent of time-of-flight cameras as well as other devices such as stereo setups, laser-range scanners and multiple view geometry systems surface shapes can be recorded easily with varying degrees of speed and accuracy. Analysis and modeling of classes of surface shapes is often based on estimated correspondences between surface points. With correspondences we can for instances quantify differences between subclasses and models can be used to extract object instances in new images. In this paper we will illustrate a novel surface registration method based on geodesic distances for analysis of facial surface scans

Registering shapes consisting of points in 3D Euclidean space, is part of the correspondence problem, where we want to locate corresponding points on different surface scans. The correspondence problem becomes very difficult to solve when operating on surfaces with large deformations and rippled surfaces.

A standard way to establish correspondences between points on a set of surfaces is to manually pick some easily recognizable landmark points, eg. nose-tip and corners of the eyes for face shapes. Once a small set of such landmark points have been selected, dense correspondence is obtained by interpolation between the landmarks. This approach is applicable for shapes with limited deformations, where a thin plate spline (TPS) warp gives an adequate and smooth interpolation between landmarks. Such an approach have been used by [1] in a modified version where Active Shape Models (ASM) [2] are constructed and works in a hybrid with the all round registration and alignment tool, Iterated Closest Points (ICP) [3].

Because a TPS warp based on a sparse set of landmarks does not reproduce foldings and other large surface deformations in between the landmarks this approach is not adequate for shapes with large surface deformations and rippled surfaces.

In [4] the registration process is utilizing the red, green and blue components of the textures and a cylindrical coordinate system of the recorded points. They implement a modified optical flow algorithm to register surfaces in this cylindrical coordinate system. Their recordings were done with a Cyberware laser scanner using triangulation and $360^\circ$ scanning.

For deformed surfaces we investigate a descriptor which is invariant to bending and deformations (as long as these deformations does not stretch the surface). This is the geodesic distance between points on a surface patch. This distance measure have been used with success to register highly curved and folded surfaces such as 3D brain scans [5] where an objective function combining geodesic distance with the surface normal and curvature is minimized.

Another use of geodesic distance for registration is reported in [6], [7]. Here each recorded face surface is mapped into a bending-invariant canonical form before utilizing a geodesic path computation method [8], [9].

Yet another approach is to optimize a measure of model complexity. One such measure is the Minimum Description Length (MDL) [10], [11]. In these approaches a initial registration is iteratively improved by perturbing points under constraints. These constraints may include point inter-distances and local curve/surface properties.

Other interesting methods includes an approach suggested by Nielsen et al. [12] who solves the correspondence problem as a geometry constrained diffusion problem.

## II. DATA

For the recording of the 3d point positions we have used a Minolta Vivid 900 laser scanner, situated at the 3D-laboratory at the School of Dentistry at the University of Copenhagen. This system works on a principle of laser triangulation combined with a color CCD camera. The scanner directs its laser on the object and the laser mark is registered in the CCD camera. Since the distance between the camera and the laser is known (both are internally fixed) a triangulation can be carried out to calculate the 3D position of the laser dot. To speed up the scanning procedure, the Minolta Vivid scanner

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sweeps a laser stripe across the object, instead of a single laser dot. The internal monochrome CCD camera has a resolution of $640 \times 480$ pixels, and RGB images are obtained by adding red green and blue filters in front of the camera. The accuracy of the registered 3d Euclidean coordinates are $\Delta x = 0.22$mm, $\Delta y = 0.16$mm,$\Delta z = 0.1$mm. Since a single scan takes a few seconds, the object must be absolutely still and attain a pose and expression which is stable for the duration of the scan.

For our expression database we have collected 35 scans of different facial-muscle perturbations of the same ID.

## III. METHODS

For the registration we choose a template shape, to which all other shapes, both ID and expression, are registered to. This template shape has neutral expression, regular polygonal grid and smooth surface.

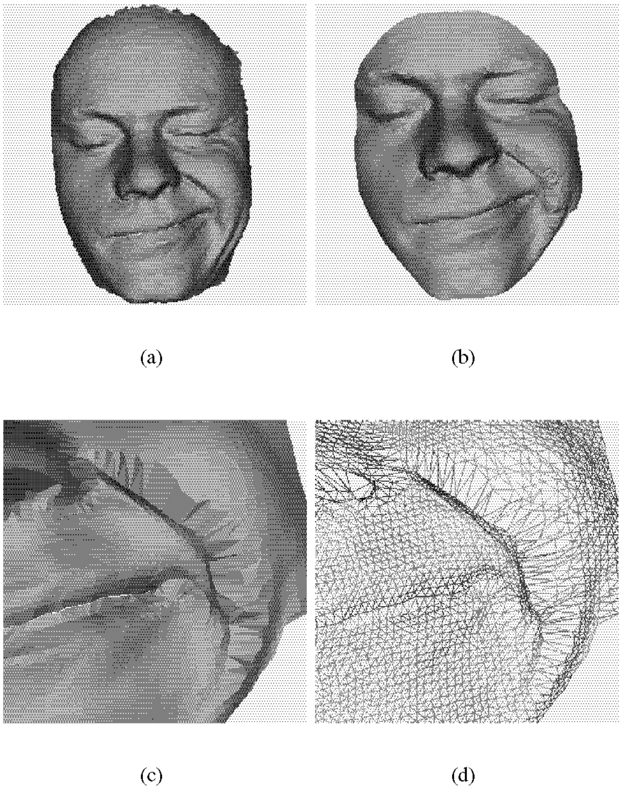

(a) (b) (c) (d)

Figure 1. Standard closest point registration. (a) Raw data; (b)The registered template; (c),(d) close up of registered template in problematic regions.

A standard registration is shown in Fig. 1. A TPS warp is applied to a set of template landmarks to warp them onto the landmarks of the new unregistered shape. The warp transform is then applied to the full template shape. A closest surface-to-point registration produces the final registered shape. In Fig. 1(a) the new expression sample is shown, in Fig. 1(b) the warped template is shown. Overall we have obtained a visually good registration, the nose-, eyes-, chin- and mouth-regions are all registered nicely. However, in the close up of the registered template in Figs. 1(c) and 1(d) we see an unsatisfactory registration of the ripples surrounding the mouth.

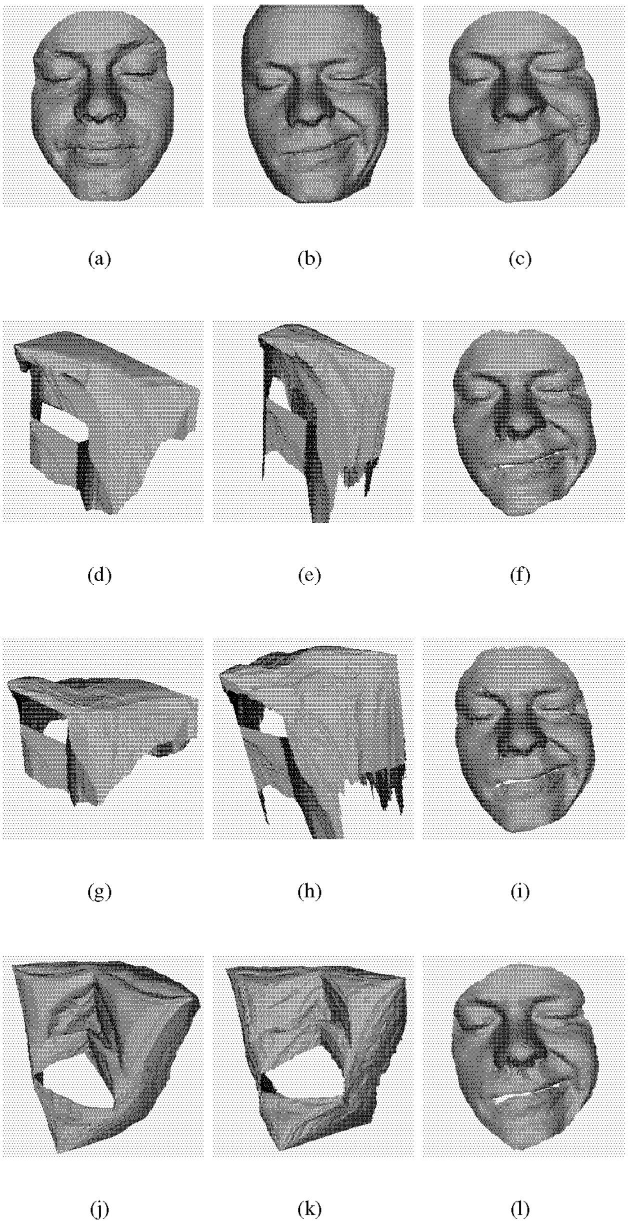

(a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k) (l)

Figure 2. The template shape and expression shapes in the mapped spaces. (a-c) template face, expression face, warped template face for the Euclidean space (d-f),(g-i),(j-l) template face, expression face, warped template face for geodesic distance spaces using three different triplets of reference points.

To overcome these artifacts, we propose to map the data into spaces where rippled and deformed surfaces are not as expressive as in the Euclidean space. One such mapping is obtained by plotting our surface in a geodesic distance space, i.e. first we calculate the geodesic distance matrix, $D_g$, where entry $D_g(i,j)$ is the estimated geodesic distance between point $i$ and point $j$. Next we pick three landmarks, $A$, $B$, and $C$, and map all Euclidean coordinates into the geodesic distance space defined by these landmarks, such that for point $i$ the mapped coordinates are; $x_i \rightarrow D_g(i,A)$, $y_i \rightarrow D_g(i,B)$ and $z_i \rightarrow D_g(i,C)$. In figure 2 three of these resulting mappings are shown for three different shapes as well as for the standard Euclidean space. As seen we obtain very different surface representations, while the shape seems similar in each mapping. For each of the three geodesic mapping representations, we apply TPS-warping and closest surface point registration, and end up with three different registrations of each shape in the geodesic distance space. Each point registration is mapped back to Euclidean space by recording the registered point triangle id and its barycentric coordinates.

None of these registrations are found to be optimal. We end up with four representations of each shape. The original Euclidean and three geodesic shapes. All registrations done in the geodesic mappings, proves to be very good at registration of the rippled regions, but they differ significantly in areas like the forehead.

Finally, a robust mean estimate of the four resulting surfaces is performed. In Figs. 3,4,5 we show the final registration result, and a zoom-in on the troublesome region. As seen we have obtained an acceptable registration, the deformed area is nice and smooth and the overall impression is good. Comparing this registration with the registration in Fig. 1(a) we observe that all artifacts are reduced significantly in the final registration.

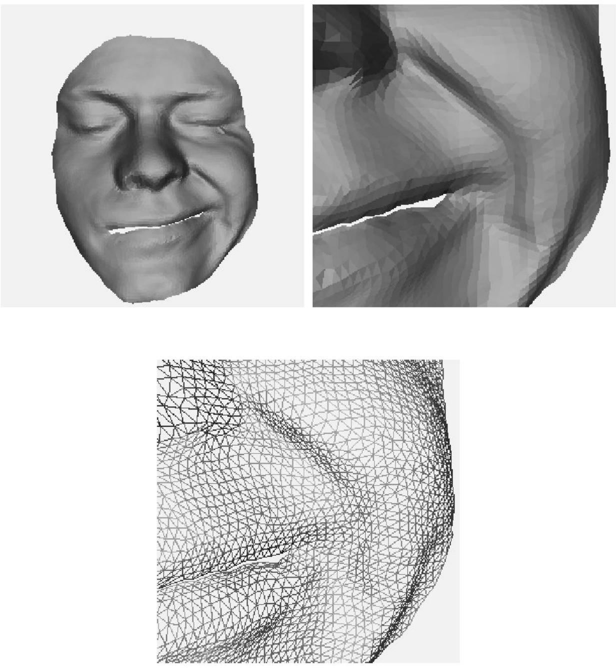
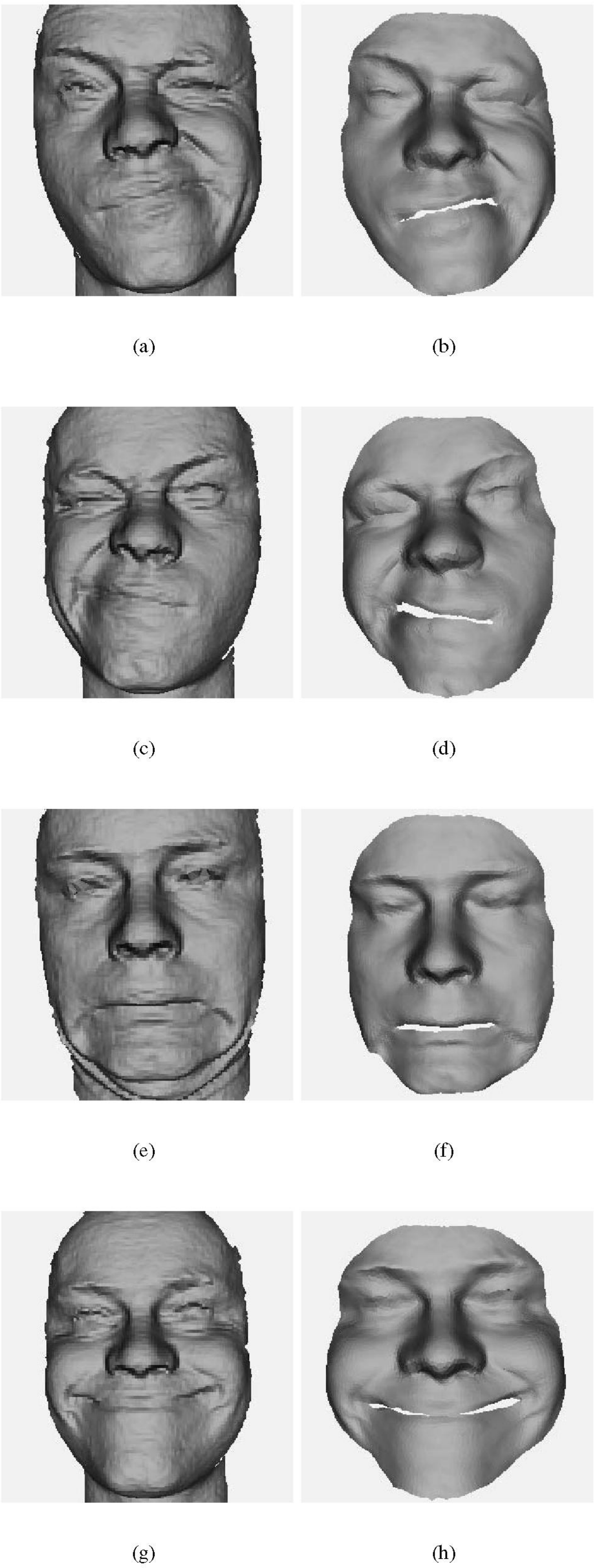


Figure 3. Final registration. Same shape as in figure 1.



(a) (b)

(c) (d)

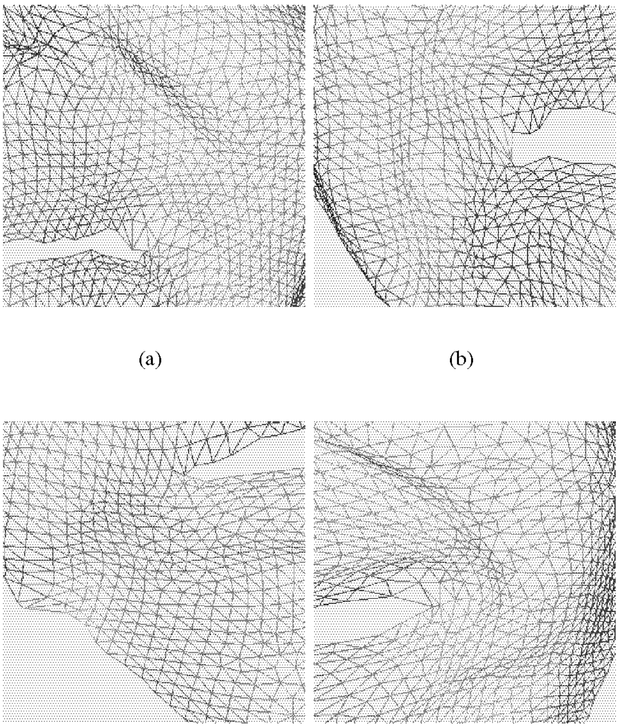
(e) (f)

(g) (h)

Figure 4. Additional examples of the registration procedure described in this paper. (a,b), (c,d), (e,f), (g,h) four pairs of expression samples and the corresponding warped template.

## IV. CONCLUSION

In this paper we have demonstrated that registration of facial shapes under expressional variation can efficiently be performed using closest point to surface registration in a series of spaces defined by geodesic distances on the surfaces to



(a) (b) (c) (d)

Figure 5. (a-d)) zoom in on difficult regions of each of the registrations shown in Fig. 4.

triplets of landmark points. This procedure out-performs standard closest point methods for cases with significant rippling of the facial surfaces - as occurs for facial expression variation.

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