Stability of feature points defined by approximating quadric surfaces - Cores 2007

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Summary. The analysis of freeform surfaces requires them to be reduced to more regular geometric structures. One approach is to approximate fragments of the given surface by quadrics, then use the points, lines, and planes defined by the quadric as bases for measurements. The present work describes a series of experiments designed to assess the stability of points defined in this way on human facial features. Both positive and negative findings are discussed.

1 Introduction

When applying computer vision to biological and, especially, medical objects, we are often confronted with the need to define visual features which have previously only been identified by human perception.

In particular, to measure distances and angles on freeform surfaces, we first have to construct geometric primitives such as points (or lines, or planes) that will define our measurements. The primitives should depend stably on surface data. In the case of polygon-tesselated surfaces, this means a primitive should be derived from a large number of mesh vertices or facets while avoiding noise-sensitive operations such as derivation or maximum search.

In the present work we shall concentrate on approximating a group of mesh vertices by a quadric surface, then taking the origins of the quadrics (i.e. the origin of the coordinate system in which the quadric has a canonical form) or their other identifiable points (e.g. saddle points, apices), as our point primitive. As quadric approximation uses statistical moments from a population of points which can be arbitrarily large, it meets our requirement that primitives not depend strongly on single mesh vertices.

Existing definitions of anatomical measurement points are usually suited for human interpretation, using highly non-linear terms such as "deepest point on the curvature at the base of the nose" [1]. "Deepest" here suggests an extreme of a coordinate, but no coordinate is defined. In this work, we try to interpret and implement these definitions, but in terms of the approximating quadrics, rather than of the raw 3D surfaces.

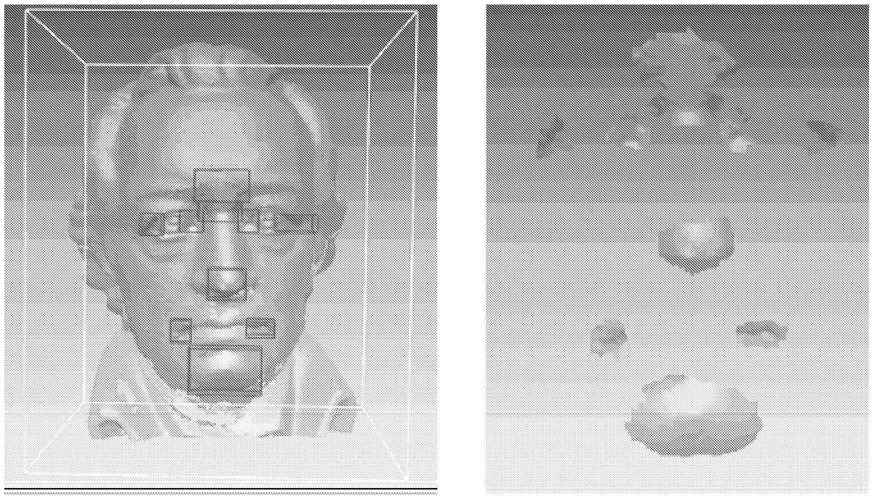

Fig. 1. Left: scanned 3D image of the bust of Goethe with frames showing selected feature areas. Right: manually cropped feature areas.

Our purpose is twofold: first, to obtain a repeatable, stable way of refining measurement points roughly indicated by a human operator. This should significantly reduce both work load and subjective error. The second and ultimate goal is to locate such points automatically. While achieving this will require much further research, the present work examines the precision of what may be the final processing stage of such segmentation.

We shall now examine the stability of quadric-defined points under the variation of such factors as instance of scanning and choice of vertex group.

2 Experiment

We used two dummy faces, to avoid shape changes due to breathing and facial expression. The actual models were the head of a doll (one with natural-looking features) and a bust of J.W.Goethe. Ten feature areas were chosen:

GB - glabella: the most prominent point on the skin above the nose
En - endocanthion: the inner corner of the eye fissure (left and right)
Ex - exocanthion: the outer corner of the eye fissure (left and right)
Hn - cutaneous nasion: the deepest point at the base of the nose
Ap - nasal apex: the tip of the nose
Ch - cheilion: corner of mouth (left and right)
Pg - Soft tissue pogonion: Most anterior point on chin in midsagittal plane

Either head was scanned three times with the Minolta Vi-9i laser scanner, from slightly different viewpoints. The resulting 6 images (3D shells) were manually cropped to leave only small areas surrounding the points in question (Fig. 1). Cropping was also performed three times, under subjective variation.

The cropping resulted in 180 small 3D images, each consisting of one surface patch representing a particular feature area of a specific scan of one of the objects (Goethe bust or doll). The patches were approximated by quadric surfaces, and the quadric polynomials used to define characteristic points.

Almost all of the features were classified into 3 quadric categories: ellipsoids, and one- and two-sheet hyperboloids (Table 1). Only one instance of cheilion was classified as a cone. Other quadric types were not represented.

Table 1. Quadric types. EL: elipsoid, 1H/2H: 1- or 2-sheet hyperboloid, CN: cone

Model	Goethe bust									Doll								
Scan	1			2			3			1			2			3		
Crop	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Ap	EL	EL	EL	EL	EL	EL	EL	EL	EL	EL	EL	EL	EL	EL	EL	EL	EL	EL
Gla	2H	2H	2H	2H	1H	1H	EL	2H	2H	EL	2H	2H	EL	EL	1H	2H	2H	2H
Po	EL	EL	EL	EL	EL	EL	EL	EL	EL	2H	2H	2H	2H	2H	EL	2H	EL	EL
CheR	1H	1H	1H	1H	1H	1H	1H	1H	1H	EL	EL	1H	1H	EL	1H	EL	EL	EL
CheL	2H	CN	2H	1H	2H	2H	1H	EL	2H	1H	EL	EL	1H	1H	2H	EL	EL	EL
Na	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H
EnCR	2H	2H	2H	2H	2H	1H	EL	1H	1H	2H	2H	2H	1H	2H	2H	2H	2H	2H
EnCL	2H	2H	EL	EL	2H	2H	1H	2H	2H	2H	2H	2H	2H	2H	2H	2H	2H	2H
ExCR	1H	2H	1H	1H	1H	2H	2H	2H	2H	1H	EL	1H	1H	1H	1H	1H	1H	1H
ExCL	1H	2H	1H	1H	1H	1H	2H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H	1H

The final result of this processing, for each scan/cropping combination, was a set of points in 3D space. The relative position of points was compared between sets in order to assess the stability of quadric-based points with respect to changing scanning conditions and subjective cropping.

Table 2. Feature dispersion and approximation error

	Goethe		Doll	
Feature	Av.D	QE	Av.D	QE
Ap	1.09	0.01	5.06	0.03
Gla	4.48	1.61	10.13	0.02
Po	3.48	0.03	2.20	0.03
CheR	3.09	3.21	3.83	0.21
CheL	7.76	8.76	4.30	0.52
Na	1.64	0.04	1.83	0.02
EnCR	4.09	1.26	1.44	0.06
EnCL	5.09	16.52	0.62	0.07
ExCR	3.81	8.29	6.53	4.53
ExCL	3.63	313.56	4.53	832.82

3 Results

Absolute feature positions can only be compared within each scan (different scans have different coordinate systems). For each scan, three positions of each feature were determined, using the three different manual croppings. The distances between such positions within each scan, averaged over the three distances per scan and over the three scans, were computed for each feature as a measure of repeatability; these average distances, in millimeters, are presented in Table 2, column "Av.D". The QE columns represent the approximation error in mm^2 per vertex in the patch.

Table 3. Avg standard deviations of feature-to-feature distances in Goethe bust...

	Ap	GB	Pg	Ch(R)	Ch(L)	Hn	En(R)	En(L)	Ex(R)	Ex(L)
GB	4,30	0,00								
Pg	2,87	4,49	0,00							
Ch(R)	2,60	3,86	1,99	0,00						
Ch(L)	3,77	7,35	5,12	2,22	0,00					
Hn	1,54	4,52	1,69	1,70	4,46	0,00				
En(R)	1,50	2,45	3,03	2,16	4,39	2,00	0,00			
En(L)	1,58	6,43	3,11	1,91	5,66	1,92	2,06	0,00		
Ex(R)	3,61	2,78	3,09	3,68	3,92	3,65	3,78	4,09	0,00	
Ex(L)	3,36	7,56	2,43	2,01	5,98	2,42	2,11	2,90	3,79	0,00

... and in doll face:

	Ap	GB	Pg	Ch(R)	Ch(L)	Hn	En(R)	En(L)	Ex(R)	Ex(L)
GB	3,76	0,00								
Pg	2,28	3,80	0,00							
Ch(R)	2,47	2,67	1,57	0,00						
Ch(L)	2,12	4,21	1,29	1,62	0,00					
Hn	1,00	3,93	1,00	1,01	1,33	0,00				
En(R)	1,07	1,83	1,28	1,03	1,44	1,18	0,00			
En(L)	1,37	5,36	0,86	0,97	0,73	0,74	0,70	0,00		
Ex(R)	3,30	2,21	2,68	3,33	2,98	3,33	3,22	2,95	0,00	
Ex(L)	3,05	7,29	0,90	1,59	2,03	1,97	1,48	1,78	3,53	0,00

4 Positive findings

Certain feature areas have proven to yield very stable approximating quadrics. One example is the nasion of the doll (Fig. 2). In this case, the approximating one-sheet hyperboloid determined the inflexion point with a repeatability of less than 2mm, even when it was outside the cropped area (Fig. 2 center).

Overall, it can be said that when a quadric does not allow a local feature point to be identified reliably, this situation is indicated by a large approxima-

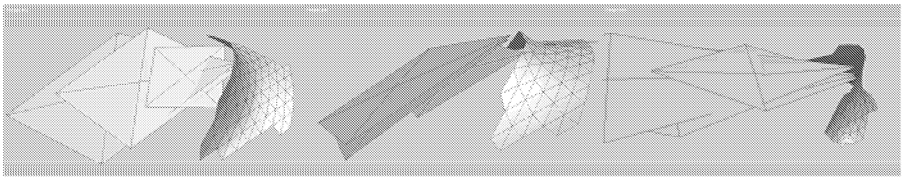

Fig. 2. The nasion of the doll face; the three pictures represent three separate scannings, and the three kite-shaped octahedra in each picture point to feature points derived from three different manual clippings of each scan.

tion error. Table 2 shows that a repeatability of less than 2mm is associated with quadric approximation errors of less than 0.1 (mm^2 per vertex).

The two endocanthions of the doll face were approximated by two-shell hyperboloids in all but sample, and Table 2 confirms that they were the most reliably localized points in the experiment. In Figure 3 the cigar-shaped octahedra indicate the feature points detected (the tip of the octahedron closest to the surface is the relevant point; the opposite one represents the apex of the other shell of the hyperboloid, which has no physical meaning).

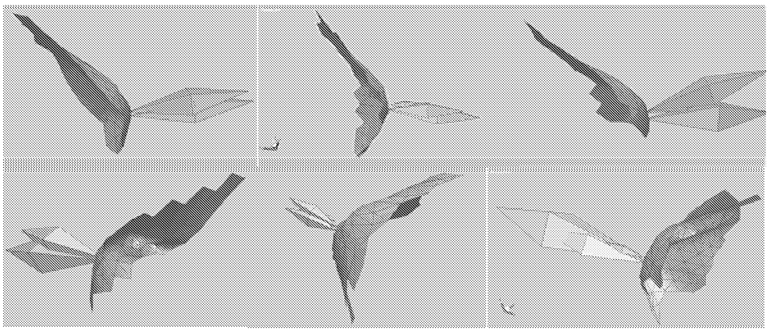

Fig. 3. Top: left endocanthion of the doll face; bottom: its right endocanthion. Three pictures of each represent separate scans. Three oblong octahedra in each picture (some occluded) pinpoint locations derived from three different manual croppings.

5 Negative findings

Some of the selected areas were not consistently represented by the same type of quadric across instances of scanning and cropping. This makes the points incomparable and essentially invalidates this part of the data. It also led to serious discrepancies in the location of resulting points. The worst case was the left cheilion (corner of mouth) of the Goethe bust (Fig. 4). While a corner of a human mouth can arguably be represented by the saddle point of a hyperbolic paraboloid, this assumption would only hold for a very small area, and consequently for a small subset of mesh vertices in our scanned images. The larger areas around the cheilion, as cropped by hand for our experiments, could not be meaningfully approximated by a second-order surface.

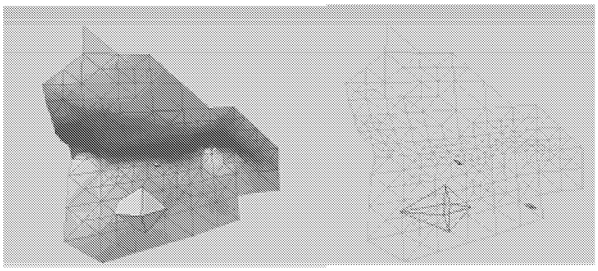

Fig. 4. One scan (third) of the left cheilion of the Goethe bust, with three different feature points determined by three different approximating quadrics. Right: the same model displayed in transparent mode to show the two minuscule octahedra. For the other scans, results were even more incoherent, and difficult to illustrate intelligibly

6 Attempts at automatic segmentation

To identify salient features on a freeform 3D surface, we sought fragments that can consistently be represented by quadrics. This part of our experiment used a live human face, as we were not testing repeatability at this stage.

The program created as many initial patches of a preset topological radius as would fit into the mesh. Then the patches evolved under five rules:

1. Expansion. A patch examines adjoining unassigned vertices to see if any of them fits the quadric currently approximating the patch. If the fit is better than a preset tolerance, the vertex can be added to the patch.
2. Competition. A patch can conquer an adjoining vertex from another patch, if the vertex fits the quadric of the former better than that of the latter.
3. Drift. A patch can "slide off" a border vertex (= one with neighbours outside the patch) if it fits its quadric less well than a predefined threshold.
4. Decay. If a patch has become too small to provide enough support for a meaningful quadric, it is eliminated and its vertices become unassigned.
5. Seeding. If sufficiently many contiguous unassigned vertices are found, a new patch is formed by the same process as created the initial patches.

The technique worked flawlessly for simple solids (cylinders, cubes etc). For a human face, setting tolerances became difficult. When tuned for looser approximations, the procedure would split the entire face into very few large ellipsoid fragments (one or two of which represented the cap over patients' hair), except for the nose which was then the only detected feature. With tighter tolerance, large uniform areas such as cheeks would split unnaturally.

More details and results can be found in [6], from where Fig. 5 is quoted:

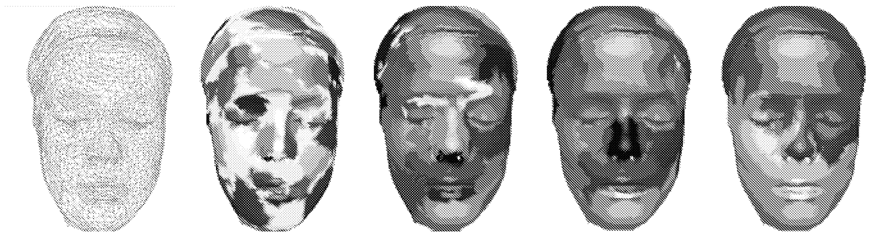

Fig. 5. Left to right: input mesh, initial patches, iterations 129, 300, and 999.

7 Seeking convergence areas

Our next experiment consisted in using each vertex of the model in turn as a seed, to start a single quadric patch of limited size and let it evolve until it reaches stability. The resulting quadric then determined a feature point (the pole of the quadric closest to the seed). After all the vertices in the model had been used in this way, distances were measured between the feature points

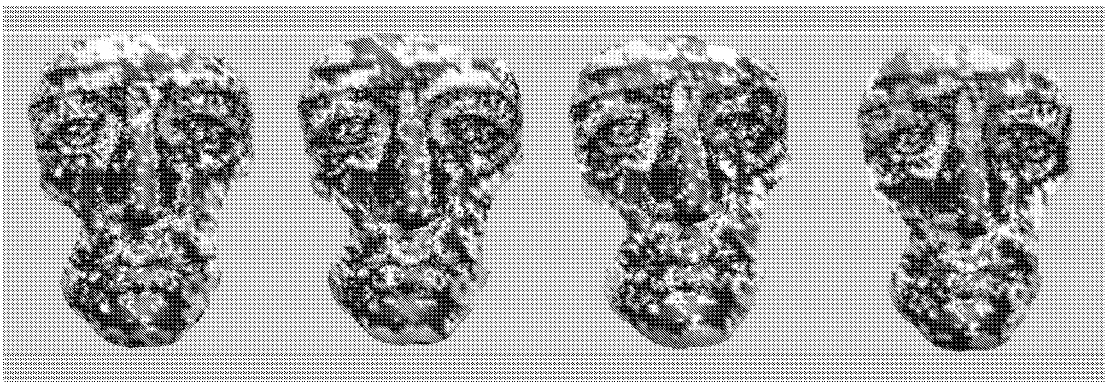

Fig. 6. Vertices of the Goethe bust classified into equivalence groups for R=2, 3, 4 and 5mm (left to right).

they yielded, and feature points no further apart than R were labeled as a group (the experiment was repeated for R=2, 3, 4 and 5mm). All seed vertices whose resulting feature points were in one group were then marked with the same colour in Figure 6. Points which did not classify into a group were colored black. The color layout confirms that certain areas yield stable quadric approximations in the sense that the feature point defined by the quadric only weakly depends on the initial point used to start the evolution of the quadric patch. Such areas include the endocanthions, the nasion, and the nasal apex, which concurs with the findings discussed in Section 4.

8 Conclusions

Quadrics have the potential to be valuable for feature localization. They are the simplest polynomials representing all the basic local properties of a surface and extracting its characteristic points; they can also define other geometric references such as lines and planes. However, no single general-purpose algorithm is likely to detect all the different features of a human face; to achieve this, a priori knowledge obviously must be used.

References

1. P.Diedrich, ed.: Ortodoncja. Rozwoj struktur ustno-twarzowych i diagnostyka (Orthodontics. Development and diagnosis of bucco-facial structures). In Polish. Wydawnictwo medyczne Urban i Partner, (Wroclaw 2004)
2. Kowalski P., Tomaka A., Lisniewska-Machororska B., Landmarks identification using active appearance models. Archiwum Informatyki Teoretycznej i Stosowanej, t. 17, , z 4/2005, pp 251-264
3. Chaari A., Luchowski L., Rousseau J., Multiple-view stereo matching of points using epipolar constraints and relaxation, Archiwum Informatyki Teoretycznej i Stosowanej, Vol. 17, No 4, 2005, pp. 241-250
4. Tomaka A., Lisniewska-Machorowska B., The application of the 3D surface scanning In the facial features analysis, Journal of Medical Informatics and Technologies, Vol. 9, October 2005, pp. 233-240
5. Tomaka A., Luchowski L., Skabek K., Tarnawski M., 3D Head surface scanning techniques for orthodontics, Journal of Medical Informatics and Technologies, Vol. 9, October 2005, pp. 123-130
6. Luchowski L., Segmenting 3d mesh images of the human face by local quadric parameterization, MIT 2006 Medical Informatics and Technology, Edited by: Ewa Pietka, Jacek Leski, Stanislaw Franiel, Wisla, 2006

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