

The analysis of three-dimensional facial dysmorphology

A grant proposal to the Wellcome Trust

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Responses to additional reviewers' comments: January 20th 2009

We are pleased by the positive and supportive views expressed by both additional referees. Only Referee 6 raised specific issues. These have been paraphrased below, together with our responses.

Referee 6

1 *How will success be measured?*

The referee will, of course, be unaware of the comments raised by the earlier reviewers and of our subsequent responses. We believe that our response 1 on the validation of the algorithms, in our document of January 10th, gives the necessary detail. Under the assumption that the committee will see all the documents simultaneously, we have not reproduced that response here. A broad summary is that we have a large collection of images on which we can develop and independently assess the proposed methods. Success can then be measured by the distances between manually and automatically identified landmarks, as well as by the reproducibility of automatic identification.

2 *Landmark-free methods are much more interesting than landmark extraction. Methods of analysis based on surface information would be most interesting of all.*

We agree entirely with this view. Nonetheless, landmarks offer a natural and well-defined starting point, from which richer representations of the images can be derived. In particular, landmarks can usefully form the anchors from which anatomical curves can then be derived. The intention, therefore, is not to restrict attention to traditional landmark methods of shape analysis but to use the landmarks as initial information from which more valuable shape information can subsequently be generated and analysed.

We also entirely agree that analysis based on full surface information is the most interesting of all and that it is likely to have the greatest potential. Even in the context of landmark identification, the use of local surface information is likely to lead to the most effective algorithms. However, for full facial representation this type of information is also most difficult to employ in a form which is amenable to analysis across patients. Several different researchers have proposed means of doing this through the fitting of standardised meshes. (Again, landmark location is the starting point for this process.) Our own current approach is documented in the paper below and we will certainly use this approach in our analysis of the data collected in the current project. However, while agreeing with the reviewer on the importance of carrying out further research on this topic, we also recognise that substantial technical effort would be required and that this would be beyond the scope of the resources already requested. We will therefore use our existing surface analysis tools within the context of the current proposal, leaving our ambitions to develop surface methods further to be pursued by other means and resources.

Z. Mao, X. Ju, J.P. Siebert, W.P. Cockshott and A. Ayoub (2006). Constructing dense correspondences for the analysis of 3D facial morphology. *Pattern Recognition Letters*, **27**, 597–608.

3 *How will difficulties due to the variation in pose be dealt with?*

This is an important issue which we have had to address in earlier studies and considerable experience in minimising the effects of pose has been gained as a result. A study of the issue was carried out and reported in the paper listed below. This gives reassurance that, with adults, pose does indeed have high reproducibility, under the controlled conditions in which we will be operating. Broadly speaking, identification of a well-defined landmark on a single image has a mean accuracy of around 0.5mm while this rises to around 1mm over repeat poses. The rise is greater for particular poses such as puffed cheeks. However, reproducibility is best for the rest pose on which the medical investigations of our proposed study is based.

D.J. Johnston and D.T. Millett and A.F. Ayoub and M. Bock. (2003). Are facial expressions reproducible? *Cleft Palate–Craniofacial Journal*, **40**, 3, 291–296.