THE ANALYSIS AND DECOMPOSITION OF FREE-FORM SURFACE MODELS

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INTRODUCTION

Reverse Engineering (RE) is a relatively new field, which aims to reproduce a physical prototype accurately. Prototype models are usually made from clay or wood, by stylists [MA, 1998], and do not involve the use of mathematical methods to determine shape [BEZIER, 1990]. RE involves the main stages of data collection, modelling and machining. In many cases, RE can be used to generate 3D shapes much faster than creating a new CAD model [PENG, 1998]. One approach to data collection utilises the Co-ordinate Measuring Machine (CMM), using a touch-trigger probe. This results in three-dimensional (3D) surface data of a physical part. Surface modelling follows data collection as the next stage of RE, where a best-fit model is generated, interpolating these data points [BARDELL, 1997].

There has been limited research in the area of surface model analysis, applied to these automatically generated surfaces. This work focuses on a novel method for analysing the accuracy of a generated surface model, highlighting regions of the surface that deviate from the CMM data. With free-form objects, deviations can be used to define the smoothness of the CMM data. With composite objects, these deviations occur at areas of extreme curvature change [BARDELL, 1998]. Surface models of this type are then interrogated, using a novel curvature-based surface decomposition method, allowing individual smooth local sub-surfaces to be modelled. This utilises a seed region growing methodology, which clusters points of the same surface type as a sub-surface, allowing assessment of the sub-surface in terms of cosmetic quality. This provides a method of determining and segmenting specific surface types from the global surface, reducing inaccuracies caused by the modelling of adjacent surfaces of differing types.

SURFACE FITTING

3D point data is utilised in a surface fitting module, where a best-fit surface is generated from the CMM points. Where the physical prototype is a sculptured free-form surface, there is generally a close correlation between data points and the surface model. Automatic modelling methods are reliable, when based on data collected in a continuous manner, despite associated errors [MENQ, 1996]. However, the surface fitting of data points collected from composite surfaces can cause inaccuracies, where the correlation between the fitted surface and the data points can vary, depending on the extent of the surface discontinuities. These deviations are unavoidable using automatic free-form modelling methodologies.

Figure 1 shows a photograph of a bottle, from which CMM scan data is collected from the neck region.

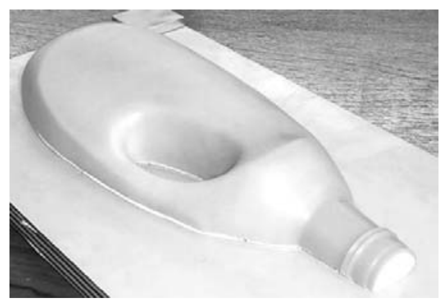

Figure 1. Photograph of bottle.

Figure 2 shows the C^1 continuous patches used to automatically generate a global surface model of the bottle (wire-frame model).

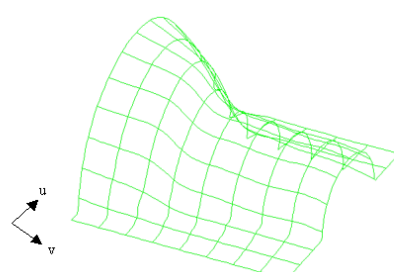

Figure 2. 10 x 8 C^1 continuous patches.

In this case, ten patches are defined in the *u* direction and eight patches in the *v* direction, with an intra-patch parameterisation of five. Figure 3 shows the rendered surface model of the same, where surface deviations are apparent.

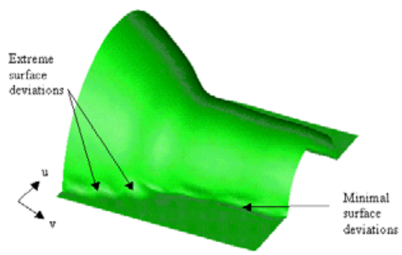

Figure 3. Global surface model.

It is at this stage, with a rendered surface model, that the major defect associated with automatic free-form modelling becomes apparent.

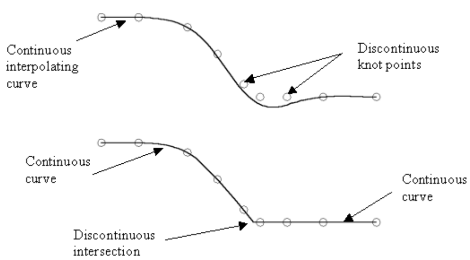

Figure 4. Forced continuity, and desired discontinuous conditions.

From the surface model, it can be clearly seen where errors in the modelling of the data points lie.

SURFACE ERROR ANALYSIS

It is desired in Part-to-CAD RE for the generated surface model to be assessed and validated. This involves highlighting any deviations of the surface from the collected CMM data, allowing action to be taken to improve the surface model accuracy, where necessary.

Figure 4 shows a schematic of how a 2D cross-section through this error region behaves, where continuity constraints affect the interpolation of the underlying parameter points. The desired modelling conditions are also shown in the lower part of the same figure, where the two curve segments are modelled with a discontinuous intersection.

Any continuous cubic B-spline will display this behaviour. This is due to cumulative chord length parameterisation and the position of interpolated knot points. The spline must deform to allow a continuous best-fit through all the points. This phenomenon is typical of rectangular Bézier patches which do not handle cusps, where the wire-frame curves force a Bézier patch to have two tangent sides [SARRAGA 1990].

To deduce, with confidence, that a generated surface model adequately represents the underlying CMM data, a novel method of surface model analysis has been developed here, based on the deviation between the generated surface and the CMM data. This is necessary, as Part-to-CAD RE gives no information on the accuracy of the model. This analysis module determines the effect of parameterisation and patch resolution on the generated surface model. Theoretically, the spline network maintains a close approximation to the CMM points, particularly with free-form surfaces. This is proven in the Deviation Analysis (DA) stage. DA determines the correlation between a surface model and the original CMM data points, by comparing the data and the resulting generated surface.

Figure 5 shows the initial results of DA, where the DA map highlights the exact location of these discontinuities, but also quantifies the deviations.

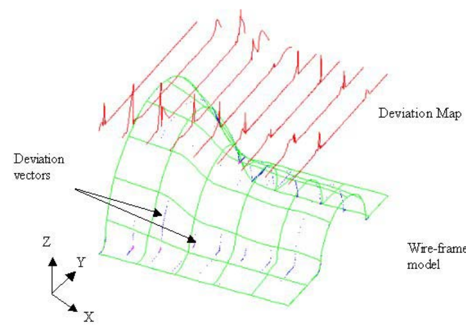

Figure 5. DA map and corresponding surface (patch resolution 7 x 5).

The development of the DA stage allows deviations occurring at discontinuous regions to be localised, and quantified. Discontinuities cannot be represented, as the global surface model interpolates the CMM data automatically, generating a best-fit surface, causing the surface model approximation errors to reduce model accuracy for composite surfaces.

SURFACE DECOMPOSITION

Part-to-CAD RE generally results in a globally continuous free-form model, constructed from CMM data points. However, in cases where the original prototype contains a number of distinct surfaces, errors occur at the surface-surface intersections. Most natural object faces are bound by crease edges, the identification of which is particularly difficult [HOFFMAN, 1987]. These are discontinuous regions which cannot be modelled accurately using continuous free-form techniques, highlighted by DA. As a novel enhancement to the RE process, the automatically generated free-form surface can be decomposed, eliminating the source of potential error.

Curvature-based surface decomposition has been developed as a 3D surface segmentation tool, specifically aimed at surfaces derived from CMM data. This involves a novel seed region growing methodology of surface expansion, which segments a global free-form surface into local sub-surfaces. The allocation of sub-surface types uses Gaussian (K) and mean (H) curvature in the locality of a data point to associate one of eight possible surface type labels to that data point [BESL, 1990], [BALENDRAN, 1992]. Clusters of points of the same surface type are then interpolated, generating sub-surfaces. Due to the potential irregular boundaries of these sub-surfaces, there may be surface interpolation inaccuracies, however the actual points labelled are well defined within the sub-surface boundary. This curvature-based method also forms a cosmetic quality assessment stage, where points on the surface which do not conform to the rest of the surface, based on a local radius tolerance, are highlighted.

The generated sub-surfaces do not have a common boundary, which is beneficial when applied to composite surfaces, as modelling errors at surface-surface intersections are reduced. These regions need ‘healing’ to introduce discontinuous intersections between sub-surfaces. This process is seen as an additional procedure, filling the intersection voids by utilising appropriate multiple surface intersection routines, common to many good CAD packages. A fillet, often defined as a degenerate patch, is traditionally inserted in regions such as these intersection voids, by the CAD operator [BEZIER, 1974]. Results of curvature-based surface decomposition involve the successful segmentation of a global surface containing different surfaces of unknown type, into a number of local sub-surfaces of known surface type. This can be applied to the analysis of sub-surface types, and the identification of regions of the surface model which have inadequate CMM data. This is useful where further data can be collected, improving the accuracy at these regions.

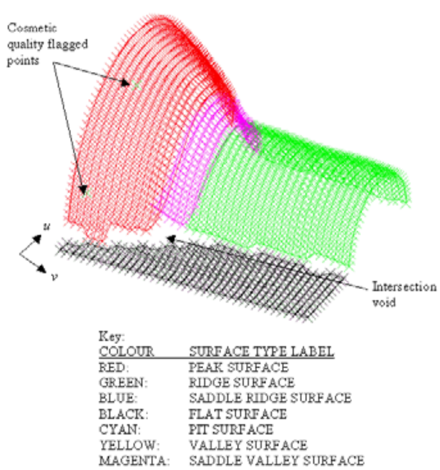

Figure 6. Result of global surface decomposition, with intersection voids.

Figure 6 shows the results of curvature-based surface decomposition, utilising seed region growing. In this case, in order to highlight the intersection voids, degenerate boundaries are modelled. This also shows points which are flagged as a different colour to the sub-surface (peak), highlighting points where cosmetic quality is compromised.

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