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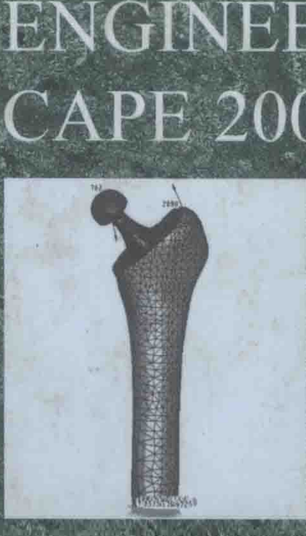

IMechE Conference Transactions

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About the Editor

Joseph McGeough is Regius Professor of Engineering at The University of Edinburgh, Fellow of the Institution of Mechanical Engineers, and Chairman of the Organizing Committee for CAPE 2000. His main field of research is in unconventional manufacturing in which he has published the books 'Principles of Electrochemical Machining', 'Advanced Methods of Machining' and is Editor of the new book 'Micromachining of Engineering Materials' to be published later this year. He has also published many papers in the learned journals.

Professor McGeough obtained his BSc and PhD at Glasgow University, his DSc at Aberdeen University, and is a fellow of the Royal Society of Edinburgh. He is an Honorary Professor of Nanking Aeronautical and Astronautical University and a visiting Professor to Glasgow Caledonian University.

Preface

On behalf of the Organizing Committee I have great pleasure in thanking you for attending the 16th International Conference on Computer-aided Production Engineering on the 7–9 August 2000. A programme of high quality research papers has been selected for presentation at the conference and I am grateful for the support of the Organizing Committee and the Corresponding Committee members for their advice in refereeing all the papers. I am appreciative of the help of the main sponsoring bodies, the Institution of Mechanical Engineers and Scottish Enterprise Edinburgh and Lothian (SEEL) in organization of the event especially Mr John Ling (IMechE), Mr Jim Reid (SEEL), and with particular thanks due to Miss Amy Middlemass (The University of Edinburgh).

A set of industrial presentations and visits have been arranged in conjunction with this years CAPE conference, as well as a social programme, which I hope will help to make the conference enjoyable for all our delegates and visitors to Edinburgh.

Professor J A McGeough
Chairman, Organizing Committee
Regius Professor of Engineering
School of Mechanical Engineering
The University of Edinburgh

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The construction of geometric models from point-cloud data

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SYNOPSIS

This paper is concerned with the utilisation of point-cloud data for reverse engineering activities and the development of geometric representations of free-form features, starting with data obtained from a digital scanning system. Consideration is given to the use of point data for the generation of CNC cutter paths and rapid prototype models, also to techniques for the construction of geometric surface representations. Particular consideration is given to the collection of point-cloud data, trimming of duplicated and redundant data, the definition of boundary curves and the establishment of appropriate continuity conditions at surface boundaries.

1 REVERSE ENGINEERING

Reverse engineering is concerned with the capture of data from existing 3D parts and utilising this to either construct geometric models or produce replicas. It is widely used in industries where it is commonplace for stylists and designers to use traditional techniques for the representation and modelling of their concepts, and for engineers to convert these models into manufactured products. Reverse engineering systems are to be found in industries as diverse as motor vehicle design/manufacture and foot wear design/manufacture.

1.1 Data acquisition

Co-ordinate measuring machines (CMM) equipped with touch-trigger probes are widely used to capture 3D geometric data, and a considerable amount of work has been done on the standardisation of programming formats and the operation of such machines. On-line and off-line programming facilities have been developed in an attempt to expedite the process of probe path planning and the generation of measurement data. Harris (1) discussed the development of one such system. Many co-ordinate measuring machines incorporate some facilities for surface data acquisition, but data acquisition rates are relatively low and this tends to limit their application to parts consisting of rational geometric features; such as cylinders, spheres and rectangular prisms. Whereas the trend is for engineering components to incorporate complex, irrational, features; such as free-form or sculptured surfaces.

Free-form features pose many unique problems for both design and manufacturing engineers. The techniques used to describe them are relatively complex; ranging from bi-parametric, bi-cubic, surface elements (e.g. cubic Bezier patches) to complete 3D surfaces (e.g. NURBS). There is no accepted standard for the measurement and representation of such features, and the problems of rebuilding geometric models from captured surface data have not been fully addressed. Data acquisition techniques for reverse engineering are usually concerned with the collection of masses of discrete position vectors (i.e. point-cloud data) in an attempt to capture all salient features on complex surfaces. Figure 2 shows the set of point-cloud data gathered from a small sculptured face. This is a very crude approximation consisting of just 2,000 vectors; many of the detailed features would be lost on such a representation. Figure 1 shows a rendered image based on the triangulation of a point-cloud data set of approximately 1.7 million vectors. This gives a much more complete representation of the sculptured face.

There are many systems used to capture shape data from surfaces, ranging from tactile probes to vision based systems. CMM with digital touch-trigger probes are generally considered to be the most accurate (with resolutions in the region of 0.005mm), but too slow when masses of data are required. Scanning systems, based on either laser triangulation or analogue contact probes, are considerably less accurate (resolutions in the region of 0.1mm) but much faster. Vision based systems are very rapid, but also very approximate (with typical resolutions in the region of 1.0mm). Consequently, vision systems are generally considered to be too approximate for the majority of reverse engineering applications.

Varady (2) presented a review of surface data acquisition techniques for reverse engineering. He concluded that tactile systems are generally both robust and accurate, and they result in nearly noise free data. The authors own work has also shown this to be the case. We have established (3) that laser scanning systems are generally faster than tactile ones, but the resulting data is often incomplete and may be very inaccurate, especially when scanning near-vertical faces. In contrast to this, tactile probing has consistently resulted in good quality point-cloud data. The work presented in this paper is based on point-cloud data acquired by a tactile, analogue, scanning system.

1.2 Point-cloud data

Point-cloud data simply consists of masses of 3D position vectors, hence it is inherently approximate and it inevitably gives an incomplete representation of scanned objects. It is analogous to the vertices in a B-Rep modelling system based on a face, edge vertex (FEV) schema. Consequently, such data gives a crude representation compared to CAD generated models. Many of the inherent advantages of CAD based modelling are therefore lost when parts are simply represented by position vectors, in particular the topological relationship between modelled features will be absent from such representations. However, point-cloud data does form a useful basis for several reverse engineering activities; such as CNC machining, rapid prototyping and the generation of surfaces for geometric modelling.

1.2.1 The generation of CNC cutter paths

CNC cutter paths for sculptured surfaces consist of many linear moves approximating the surface curvature. The degree of approximation being controlled by chordal deviation tolerances set at the tool path planning stage. Tactile systems for the collection of point-cloud data generally use chordal tolerances in a similar way. Consequently the format of point cloud data is well suited to the generation of cutter location data and CNC cutter paths. Lin (4) presented a description of a system which automatically generates three-axis cutter paths from such data. There are also several commercial systems available for the collection of surface data and the generation of CNC cutter paths. The CYCLONE™ scanning machine (figure 4) and TRACECUT™ software, from Renishaw plc, is one such example. This system utilises an analogue, tactile, scanning probe to collect point-cloud data, which then forms the basis for tool path planning in the TRACECUT™ software. Facilities such as chordal tolerancing, scaling, male to female translations and off-setting of the scanned data are facilitated. Off-setting is required to compensate for the radius of the spherical probe tip in order to generate actual surface geometry (rather than geometry relating to the centre of the probe tip). This can be accomplished within the software, but one pragmatic approach is to use a finishing cutter with the same tip radius as the scanning probe; thus obviating the need for probe tip compensation.

Cutter paths generated directly from point-cloud data generally produce very satisfactory results. Particularly if the cutter size is large compared to the pitch of the surface data; under these circumstances the cutter will track across the data and automatically fill in any gaps or voids in the point-cloud. It is commonplace for machine shops to generate CNC cutter paths on massive point-cloud data consisting of many millions of vectors.

1.2.2 Rapid prototypes and shading

Point-cloud data may be relatively crude and incomplete but it can form a very useful basis for the generation of shaded images and data for a wide range of rapid prototyping processes.

Using planar facets to link the vertices in a set of scanned data will result in a tessellated surface. The degree of facetting being dependent on the density of the point-cloud data and tolerance applied to the fitting algorithms. Triangular facets are often preferred for shading and rendering, and they are used extensively to produce images of geometric models. Applying triangulation and shading directly to a set of scanned data can give very acceptable results, as shown in figure 1. This tessellated representation is still far short of a complete geometric model, although triangular meshes are often employed as an intermediate stage in the process of curved surface reconstruction (5).

Rapid prototyping processes are almost exclusively based on the notion of representing 3D objects as sets of 2D cross-sections. A review of these processes is beyond the scope of this paper, but it is worth noting that the starting point for most rapid prototyping systems is a tessellated representation in the standard triangulation language (STL) format. Triangulation of point-cloud data is a relatively straightforward operation (see above) and there are commercial systems with the capability of generating STL files directly from such data. The TRACECUT™ software is one example of this. The conversion of point-cloud data into rapid prototype models is therefore considered to be relatively routine.

1.2.3 Data for transfer to CAD

Point-cloud data is not sufficient for the complete representation of geometric models, but it does form a useful basis for the generation of such models. The challenges inherent in progressing from a set of points to a complete and consistent CAD model are well documented by Varady (2) and Puntambekar (6). Essentially these consist of the creation a series of boundary curves and fitting surfaces to these and the point-cloud data, with the aim