Institution: Edinburgh Research Partnership in Engineering – ERPE (Heriot-Watt/Edinburgh)

Unit of Assessment: B15: General Engineering

Title of case study: Feature Recognition For Smart Design And Manufacture

1. Summary of the impact (indicative maximum 100 words)

In 1997 ERPE invented a novel automatic machining feature recognition technology which has been incorporated into the Pathtrace EdgeCAM Solid Machinist Computer Aided Manufacture (CAM) package, now owned by Planit plc. EdgeCAM is considered as one of the leading independent solid machinist CAM package, with 10 – 15% of the world market. Related ERPE feature recognition in shape representation and characterisation has enabled the design of a 3D shape browser for product data management systems. Commercialised in 2005 as ShapeSpace with £0.7M current market value, for application to the parts industry in automotive markets, it has attracted the US Actify Inc., as an equity sharing partner to aid ShapeSpace to access worldwide markets.

2. Underpinning research (indicative maximum 500 words)

The ERPE research team comprises Profs: Corney (left 2007); Clark (retired 2003); Lim, Senior Lecturer Mill, with Prof Taylor from Computer Science (all in post throughout the period unless stated). Former lecturers are Salmon and Sherlock, and former PDRAs: Little; Tuttle; and Sormaz.

Advances in feature recognition for parts machining was motivated by industry's need to create a faster, more efficient and robust Computer Aided Manufacture (CAM) system. Corney, Clark, Little, Tuttle and Sormaz first applied computational geometry with graph theory to identify numerically controlled (NC) machining features from solid models [1]. This early implementation was novel but was limited to only prismatic shapes. Lim then refined and extended this to curved and complex surface geometries [3].

The ability to automatically find machining features on curved and prismatic components interested Pathtrace (developers of EdgeCAM) and subsequently resulted in a knowledge transfer programme. Little (1998) moved to Pathtrace to implement the first development as an AutoCAD plugin. Lim (1999) then worked in Pathtrace to demonstrate the effectiveness and robustness of the new automatic feature recognition algorithms and incorporated them into EdgeCAM.

The research was incorporated into Pathtrace's roadmaps towards achieving highly intelligent CAM systems. The novel design and packaging of the algorithms showed that it is highly scalable, tractable and adaptable to function as the core architecture in solids machinists' software systems. This is extremely important as feature finding is today a key element when preparing solid parts for manufacturing [2].

A related commercialised research activity, ShapeSpace Ltd, founded by Sherlock and Mill was originally aimed at developing new geometric reasoning algorithms to support design activities and aid the description of parts to assist identifying their location within a large stock or database. This researched the development of a 3D browser that enabled efficient searching for models and other design data with the patent application now filed in 2011 as US 13/698809, with a priority date of 18/05/2010.

Initial research [4] (Salmon to 2000) was based on the development of high level design tools which incorporated a rich set of information in addition to geometry. These 3D feature enhanced CAD modellers were aimed at improving general company activities such as management and manufacturing functions. This led to research that was concerned with the representation of parts and their associated data [5], and developing more flexible approaches to dealing with the associated manufacturing information. This in turn led on to exploring the specific problems of finding product-related data in large company file systems and intranets. Collaborating with partners in Europe and Corney's group permitted superior algorithms to be developed that would

allow engineers to more efficiently search for complex design data in a flexible way. A major innovation was the development of shape based search methods to support human computer interaction [6] with Taylor.

The foundations of this research can be traced back to Mill's awards (GR/K53659/01, GR/J40713/01, GR/F92312/01 totalling £272k in association with GEC Marconi, Rolls Royce, BAE Systems and Logica), the EC/BRITE-EURAM award SESAME grant, £235k, with Spatial Technology Ltd./Strassle GmbH/MandelliSpA which supported the basic engineering work in shape representation and characterisation, particularly in feature-based design and shape optimisation.

There is now a centre of expertise based around the Edinburgh offices of ShapeSpace, with its US partner Actify Inc., and through ongoing collaborations with the ERPE and Strathclyde.

3. References to the research (indicative maximum of six references)

References identified with * are those which best indicate the quality of the underpinning research.

[1] *Tuttle, R., Little, G., Corney, J, and Clark, D.E.R., "Feature recognition for NC part programming", Computers in Industry, Vol. 35, No. 3, pp. 275-286, April 1998 DOI: 10.1016/S0166-3615(97)00089-4. 22 Google Scholar (GS) citations.
This paper reports the automated recognition of manufacturing features on solid models of polyhedral objects to support the generation of NC machine code for process planning and manufacturing.

[2] *Lim, T., Corney, J. and Clark, D.E.R, "Exact Tool Sizing for Feature Accessibility", International Journal of Advanced Manufacturing Technology, Vol. 16, No. 11, pp. 791-802, 2000. DOI:10.1007/s001700070013. 26 GS citations.
This paper presents an algorithm for calculating the volume of a 2D-profile, accessible by a given diameter of milling cutter. Exact results are obtained despite simplicity of this procedure.

[3] Lim, T., Corney, J. and Clark, D.E.R, "Laminae-Based Feature Recognition", IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 23, No. 9, pp. 1043-1048, 2001. DOI:10.1109/34.955117
This paper presents a novel approach to recognizing shape features on geometric models using a network of adjacent 2D-laminae or bounded surfaces.

[4] Naish, J., Mill, F. and Salmon, J, "An Industry-based Study of Cutting Process Capability: Representation Requirements for an Integrated Simultaneous Workstation", Institute of Industrial Engineers (IIE) Transactions, Vol. 29, No. 7, pp. 573-584, 1997. DOI:10.1023/A:1018501530306
This paper uses a library of volumetric features to build 3D models that are typical of those created by cutting and milling processes.

[5] Baron, P., Fisher, R., Mill, F., Sherlock, A., and Tuson, A., "A voxel based representation for evolutionary shape optimization", Artificial Intelligence for Engineering Design, Analysis and Manufacturing, Vol. 13, No. 3. pp. 145-156, 1999. DOI:10.1017/S0890060499133031. 12 GS citations.
This shows how any arbitrary part can be approximated with the voxel based representation. This can be used as a suitable representation for a genetic algorithm based shape optimization.

[6] *Clark, D.E., Corney, J.R., Mill, F., Rea, H., Sherlock, A. and Taylor N.K. "Benchmarking Shape Signatures against Human Perceptions of Geometric Similarity", Computer Aided Design Journal, Vol. 38, No. 9, pp. 1038-1051, 2006. DOI: 10.1016/j.cad.2006.05.003. 10 GS citations.
Methods that have been developed to automatically characterize 3D shapes in large databases are compared to methods based on human judgment to test the researchers' algorithms.

Further Grant funding:

[G1] SERC/ACME, £130k, "Genetic Algorithms in Manufacturing Engineering", 1993 - 1996, with Rolls Royce/British Aerospace/University of Sussex.

[G2] ESPRC, GR/K48020/01, £268k (Pre-FEC), Corney (PI) "Feature Recognition For CNC Part-Programming", 1995 – 1998

[G3] ESPRC, GR/N21307/01, £176k (Pre-FEC), Corney (PI), " Part Sourcing In A Global Market", 2000 - 2003

[G4] ESPRC, GR/R35285/01, £179k (Pre-FEC), Corney (PI) " Assembly Based Rapid Prototyping" 2001 – 2003

4. Details of the impact (indicative maximum 750 words)

ERPE researchers have advanced and contributed to the science of automatic feature recognition.

This research was critical to the development of the feature finder functionality now incorporated in the EdgeCAM "Solid Machinist" module and brought the product to market significantly quicker than would otherwise have done [S5]. According to the Software Development Manager, Vero UK (Planit's parent company), "*This work brought Solid Machinist to market quicker and some of the algorithms are still in use. The technology was part of the reason why Planit PLC bought Pathtrace in 2006, as the vital part of the functionality in EdgeCAM was the principal product of Pathtrace"* [S1]. Solid Machinist is used by customers all around the world for milling and turning of components, modelled in various different CAD formats.

EdgeCAM Solid Machinist uses automatic feature recognition [1, 3] to interrogate the solid model and quickly identify machinable features. EdgeCAM then offers the user the most appropriate tooling and machining strategy to generate accurate toolpaths [2]. "*The research developed collaboratively with ERPE provided the building blocks of the software used by our core customers in industries such as aerospace, automotive, energy and medical sectors. From a position where 7 years ago, 20% of our customers used the software, to approximately 65% of our customers using the software now demonstrates that the integrity of the collaborative research means that the technology meets customer needs more closely. Without strong University collaboration, developing sustainable R & D is very difficult to justify financially for a company like EdgeCAM. While it is considered one of the world's leading independent solid machinist CAM package, with 10 – 15% of the world market, the demands on the business mean that there is little capacity to undertake such high risk work."* Senior Manager at EdgeCAM. [S2]

The related company ShapeSpace Ltd., was developed to provide leading edge tools to design engineers and to those concerned with the management of design data. With Scottish Enterprise and Royal Society of Edinburgh support in 2005, through an Enterprise Fellow award, Sherlock launched ShapeSpace. Private funding and a SMART award led to the development of search software for engineering and manufacturing companies in 2008.

A specific problem addressed is the location of product-related data in large file systems and intranets. The ERPE 3D shape browser was thus designed [4, 5] to allow engineers to search for product data in their management systems or databases via the associated part shapes. This enables design re-use, better file management through the identification of duplicate and similar parts. Additionally recent collaborations have led to the development of tools that assist managers to better view the state of the total design effort for new products.

"One of the most costly overheads of 3D CAD design and modeling is the creation of stock parts. ShapeSpace makes searching for these, sometimes mislaid, parts a fast and intuitive process and has already saved me hours spent recreating already existing models…We model shapes in 3D so what better way to search for them than in 3D!" Senior Design Draughtsman, Chemring EOD Ltd., [S3].

These tools have led to directly sellable products that are now offered by the company and its long term development plan is based on ERPE collaboration. In 2008 the company's strategy changed to develop expertise which would make them recognized as world experts in part searching technologies and in the representation of complex product data. This led to the ShapeSpace partnering with Actify Inc., (a San Francisco based software company) on an initial two year contract with Jaguar Land Rover for the supply of product status tracking software for all new vehicle programs in development.

In October 2012, the formal investment and equity sharing arrangement with Actify Inc., http://www.actify.co.uk/resources/press-releases/812-2/, led to the opening of a joint office [S6] with a new period of growth to access to new markets, especially automotive industries in the US and Germany, and the continued development of new products around data analytics and business intelligence for discrete manufacturing. Currently, 6 people are employed in the Edinburgh office. ShapeSpace current market value, calculated on recent share trades is around £0.7M, following the significant investment by Actify.

The new products, which enhance the original technology, in the area of data analytics for product data which result from the 2012 SMART award, have seen significant traction in the market both in the UK and globally. Current customers include Jaguar Land Rover, Weir Group, CSC, JCB, Lucy Switchgear in the UK and Exterior Systems Engineering, Benteler Automotive Corporation, Magna Inc, Complete Prototype Services, Inc., Inalfa Inc, Dienamic Tooling Systems, Inc and Autotek Mexico, S.A. in North America.

"*The research at the University of Edinburgh on geometric reasoning for shape recognition was instrumental in the development of the technology that underpins ShapeSpace's growth in the area of data analytics for engineering and manufacturing industries. The University's support of Andrew Sherlock's academic career, which led to him securing the Royal Society of Edinburgh-Scottish Enterprise funded Enterprise Fellowship, very successfully enabled the formation of our company, ShapeSpace*." Senior Software Engineer, ShapeSpace [S4].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] Software Development Manager, Vero UK, see comments included in Section 4.

[S2] Senior Manager, EdgeCAM, see comments included in Section 4.

[S3] Senior Design Draughtsman, Chemring EOD, Ltd., see comments included in Section 4

[S4] Senior Software Engineer, ShapeSpace, Ltd., see comments included in Section 4.

[S5] Sales Manager, Pathtrace will confirm that this work was critical to the development of the feature finder functionality incorporated in EdgeCAM "Solid Machinist" module and brought the product to market quicker than would otherwise have done. Solid Machinist is used by customers all around the world for milling and turning of components, modelled in CAD formats.

[S6] http://www.actify.co.uk/resources/press-releases/actify-opens-new-office-in-edinburgh-scotland/ details the Actify relationship with Shapespace.