SUPPORTING DESIGN FOR MANUFACTURE THROUGH NEUTRAL FILES AND FEATURE RECOGNITION

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Abstract. To reduce the non-recurring design costs of creating a new product, Knowledge Based Engineering developers must strive to combine design tasks with downstream processes, including analysis, manufacturing appraisal, process planning and inspection activities. To facilitate the transfer of data between design companies and those involved in downstream activities we propose that the IGES neutral CAD format and a wireframe model is useful for supporting concurrent engineering objectives and enhancing contemporary Feature Recognition (FR) processes. The creation of an Intelligent Design Advisor (IDA), combining broad range FR with manufacturing knowledge has the potential to reduce design cycle time in the concurrent engineering environment. The IDA captures company knowledge and intellectual property from experts and supports designers by offering or substantiating manufacturing alternatives satisfying functional and economic measures.

Introduction

To be successful, an engineering company must aim to reduce the non-recurring design costs of creating a new product, without diminishing quality standards. To facilitate such a cost reduction, companies must combine the design task with downstream processes, including analysis, manufacturing appraisal and process planning and assembly and inspection activities [1]. There are a number of computer-based tools in the industry with the purpose of reducing the 'over the wall' approach to engineering design, however they do not bridge the gap between downstream processes like manufacturing analysis and the upstream processes of conceptual design where the most impact can be realised. There is a need, therefore, for engineering companies to develop Knowledge Based Engineering (KBE) tools to automate the process of integrating design and analysis. This paper suggests a method for providing information about the product model to downstream processes, thereby reducing problems associated with interacting with product designs at the initial, or conceptual phase.

Computer Aided Process Planning (CAPP) software automates the process of matching a product to a manufacturing process traditionally undertaken by a human expert. This process involves a number of key steps:

1. Interrogating and interpreting a product Computer Aided Design (CAD) model for its key features;
2. selecting a machine capable of manufacturing these features, and;
3. creating a sequence of activities to have the selected machines create the product described by the geometry of its CAD model.

CAPP software tools are useful for reducing demand on skilled human experts and ensuring the production of consistent process plans through eliminating redundancies and conflicts that arise in complex designs. CAPP tools are, unfortunately, not as adept at dealing with variations in product topography as human experts. Additionally, manual feature recognition is a time consuming task. For the human expert, when experience and creativity are not capable of producing a viable manufacturing process plan, the original design must be modified. Contemporary CAPP software does not yet have the ability to interact with the engineering designer sufficiently early to reduce the chance of creating an uneconomic design or one that cannot be created. The ability to provide feedback for the engineer as the product design is progressing is important because:

1. Upwards of 80% of final product cost is determined at the design stage [2];
2. It is often difficult for a designer to remain abreast of advancements in their own field without the added burden of keeping up to date with advances in manufacturing capability and economics; and
3. Inexperience of new designers contributing to more manufacturing design reviews than might otherwise be necessary.

Additionally, CAPP software tends to be limited by restriction of manufacturing domains in terms of process planning and ability to recognise types of design features contained within the product CAD model. Salomans suggests that using knowledge of design features from CAD software used to create a product model, known as feature based design, involves the translation of feature information from one type to another and is inefficient [4]. From the perspective of feature-based design, an example might be the conversion of design features in the product model to manufacturing features useful to a CAPP system as described in Figure 1.

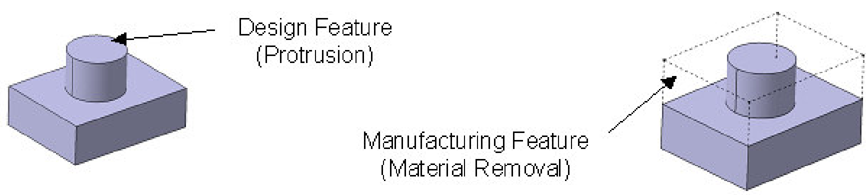

Figure 1: Example of Design Features vs. Manufacturing Features

A new methodology is required to overcome both the limitations of recognising features in complex problems and the limitations on manufacturing domain knowledge prevalent in current implementations of CAPP software FR techniques.

Feature Recognition

Feature recognition is an automated method for identifying and extracting features from a CAD product model for the purpose of finding manufacturing or analysis information about the product. Automating the extraction of design features from a CAD model has a positive effect on reducing lead-time of activities downstream of engineering design. The role of feature recognition in relation to manufacture is depicted in Figure 2. Mainstream contemporary computer aided design modelling software utilises a design by feature methodology. Automated recognition of the features of a design should therefore be a simple matter of citing the feature elements defined in the original CAD product model. The disadvantage of this approach is that, as shown in Figure 1, the features utilised within a product model may have different interpretations within different domains. For example, features that support manufacturing analysis differ from features that support stress analysis and so on [3]. Geometry, therefore, remains the most important characteristic of a product model in feature recognition processes as it is consistent across all domains. Feature recognition algorithms may therefore be selected without regard for an existing feature's utilisation. This implies that there are no disadvantages in using a non-specific file format, for example neutral files such as IGES, over a proprietary CAD file format for the purpose of feature recognition.

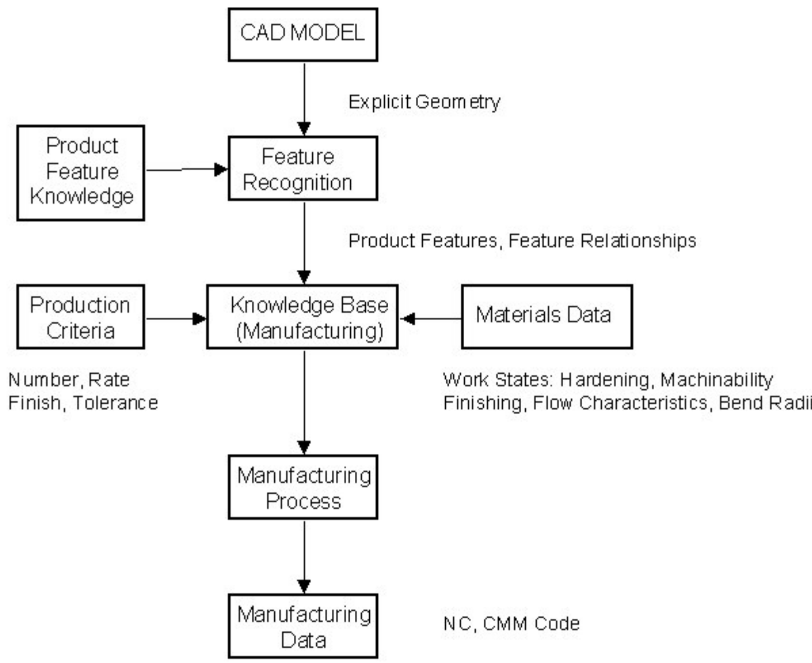

Figure 2: Feature Recognition in Relation to Manufacturing Analysis.

Current literature covering feature recognition highlights the difficulty associated with developing a generic feature recognition method that can be successfully applied to design, manufacture, analysis or other aspects of the product development process. The domain of a generic feature recognition tool is potentially vast, even if constrained to certain products and materials, like aerospace metals for example. A number of solutions have been put forward to solve this problem that include:

1. Development of new Design by Feature (DBF) CAD systems with more robust feature descriptions [3].
2. Application of rigorous naming conventions to track the interaction of different features [5].

Whilst these methods may go someway towards solving the problems associated with finding features in the first instance, they do restrict the software that may be used in terms of the focus of utilisation such as Design for Manufacture (DFM) or analytical or detail design. Additionally these methods not deal with the problem of applying FR techniques to legacy product models, which are a source of valuable Intellectual Property (IP) retained by an organisation. What is required is a combination of various FR algorithms, each successful at solving a small aspect of the overall domain. This approach has the potential to create faster, more efficient, and more importantly, more robust solutions than are currently possible. With prior knowledge of the engineering intent implied by the product model, the user may manually select limited groups of feature recognition algorithms to enhance the execution speed of the combined FR processes. This is important, as low speed of operation, and computational resources required by some feature recognition algorithms may be excessive for the requirements of a specific application. For example, consider a product model in the conceptual design phase for which a basic appraisal of possible manufacturing processes is desired, but for which no detailed geometry exists.

In order to facilitate the successful combination of independent FR algorithms, we propose that a common standard be used for examination by all FR routines applied to a problem. Such a standard would require:

1. Consistent input data;
2. Dependency on geometry only; and
3. An ability to retain and utilise legacy knowledge held by a company.

Such a standard would also alleviate problems associated with transferring product models between organisations.

Data Exchange Issues

It is generally accepted that there are two methods of identifying features in a CAD model:

1. Capturing features as they are created; and
2. Identification of features after creation, by post-processing.

For companies whose focus is in providing engineering design services to a client, the latter method is often the preferred one. This is because such companies must cater for a wide variety of CAD formats whilst, at the same time, ensuring a competitive resource profile in terms of carrying a high investment in manpower and CAD software skills and licenses. The design and manufacture of engineering products typically involves the transfer of information between designers and manufacturers, which are usually located in different companies and often in different countries. Although each company will have different requirements of its software, the CAD product model is the most important embodiment of design and manufacturing knowledge of the product. Supporting the Product Data Management (PDM) system of a customer requires dealing with:

1. Proprietary 3D CAD modelling software; and
2. Modelling practices and techniques, including colours, layers and order of geometry creation.

The overhead that comes with conforming to the PDM system of another company may be overcome by the use of software independent formats for storing model geometry. The International Graphics Exchange Format (IGES) and Standard for Exchange of Product Model Data (STEP) are both non-proprietary international accepted standards and often referred to as neutral formats [6,7]. A brief comparison of these two standards is shown in Table 1. The use of neutral files offers a number of advantages to the KBE software developer. A company can remain independent of the CAD software used by a client or customer and utilise their core competencies related to their choice of engineering software and, as has been mentioned already, the features of a product when interpreted in one domain, like design, are not generally of use in other domains like manufacturing or analysis. Additionally, neutral files offer independence of the modelling techniques that have been used to generate the product model geometry through rewriting the product feature tree with consistent geometry types and no parent/child relationships. Of particular benefit to feature recognition processes, this marshalling of product geometry into a structured format through the use of neutral files permits simpler aggregation of multiple smaller feature libraries. This is useful in decomposing the problem so that combined algorithms suitable for identifying the most suitable set of features of a geometric shape can be used. Finally, the removal of both design-by feature information and feature creation order reduces the overlap between individual FR algorithms and allows the developer to focus on the manufacturing and analysis aspects of a part without influence from the design processes.

Feature	**IGES**	**STEP**
Level of Automation	Moderate – user control required	High
Wireframe Geometry	Excellent	Good
Surface Geometry	Excellent	Good
Solid Geometry – CSG and B-Rep	Poor for most CAD software	Excellent
Non-geometric data transfer (drawings, etc)	Yes	Controlled by AP
Layers and colours	Yes	No

Table 1: Feature Differences between IGES and STEP

Unlike IGES, the STEP specification does allow for notes and other text or descriptive information to be included in a file, however it must be either added manually by a user, or requires the use of a custom STEP file writer. Whilst many Application Protocols (AP) exist, for an automated knowledge-based application, STEP is not suitable for the purpose of conveying feature data if:

1. The CAD package in use does not recognise the AP being used by the customer; or
2. If the customer has used a more widely accepted AP without the same capability.

Similar results may be obtained by augmenting the IGES format with the use of:

1. A text file or similar, external to the CAD file, containing feature data, material information and other attributes of the product. The process of creating this file loses a little of the automated or generative form that a design service provider would require;
2. A CAD file naming convention that conveys information about the types of features, material and design constraints inherent in the product model.

Wireframe models are now seldom used for creation of complex solid models, even though they are easily generated by using neutral file formats like IGES and STEP. Unlike solid models, wireframe models are computationally undemanding to handle but, like surface models, they can become ambiguous when determining what is 'solid' and what is a removal volume. This ambiguity may be too difficult for an automated feature recognition system to handle. However, the speed and simplicity of analysing a wireframe model is significant enough when compared to surface and solid based models to make this approach worthwhile. A comparison of the benefits of different CAD model representations is shown in Table 2.

Attributes	Wireframe Model	Surface Model	Solid Model CSG	Solid Model B-Rep
Complexity	Low	Moderate	High	High
Computation Resources	Low	Moderate	Highest with evaluation of solid	High
Geometric Ambiguity	High – Human Interpretation	Moderate	Low	Low
Representative of Solid Geometry	Difficult	Easy	Easiest for simple parts – tree can be complex for fillets	Easiest
Suitability for NC/CMM tool path generation	Medium	High	High	High
IGES Capability	High	High	Restricted	Restricted
STEP Capability	Restricted	Restricted	High	High

Table 2: A comparison of relative CAD Model representations (Adapted from [8])

For product shapes that do not include complex freeform surfaces, like those found in the construction of aircraft internal structure for example, surfaces can be generated from the set of curves supporting the surface boundary if required. This is commonly useful for ascertaining the penetration of one feature by another. The wireframe model does have a unique performance advantage for supporting feature recognition processes. Penetrating features have new geometry created in wireframe that is not present in surface and solid models. When a surface is penetrated, by a projection or pocket for example, a new set of curves is generated, highlighting the boundary of this feature. We suggest that IGES neutral format is a superior choice for feature recognition processing when compared to STEP in terms of speed and computational resources when used in conjunction with a wireframe model as highlighted in Table 1 and Table 2.

Methodology

The employment of domain indefinite feature recognition processes and neutral file formats has the potential to assist development of KBE applications by reducing dependence between customer-client data management systems and reducing the computational resources and time required to extract broad ranging features from computer product models. These methods are being utilised in our current development of an Intelligent Design Advisor (IDA) for supporting the conceptual phase of engineering design [9]. An IDA, as seen in Figure 3, supports design processes in the context of concurrent engineering by matching design features of a CAD model with manufacturing process knowledge, providing feedback on manufacturing options to the designer. At the conceptual design phase, there is comparatively little information available to support product costing, however with knowledge of relative economics of manufacturing processes, product features and material combined with production batch sizes, the designer is able to focus detailed features of the design on the suggested manufacturing solution. Such a method is preferable to the traditional ‘over the wall’ approach to design for manufacture, and further reduces design cycle time in an existing concurrent engineering environment.

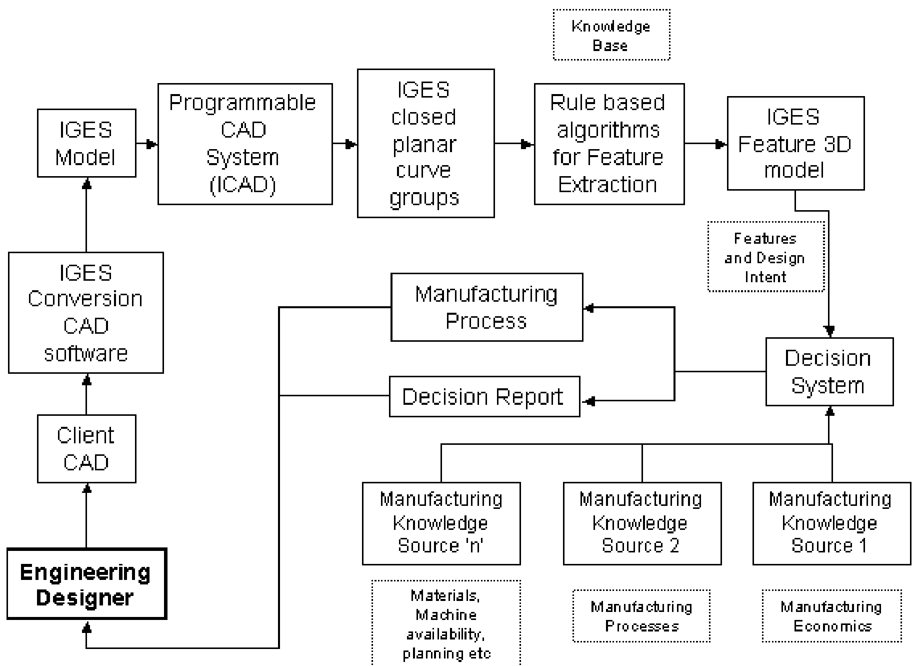

Figure 3: Overview of Intelligent Design Advisor for Manufacturing

Creating a feature recognition composition of algorithms to support a design advisor must be augmented by:

1. A decision making mechanism;
2. A Program Interface for user feedback concerning product features; and
3. A knowledge base of manufacturing knowledge as it relates to features of design, together with relative cost differences between processes.

The decision-making system uses feature recognition processes to extract information from a product model and is passed to a user for confirmation of material, tolerance and batch sizes. Utilizing a knowledge base for manufacturing process capability we are developing an algorithm for assisting the engineering designer in selecting a manufacturing process satisfying functional criteria at lowest cost. If maintained by a manufacturing company, an Intelligent Design Advisor for manufacturing may allow the engineering designer to remain abreast of available production capability without the supplementary burden information gathering outside of their own discipline. The IDA will have the potential to reduce feedback time between manufacture and upstream conceptual design to minimize the overall design cycle time, particularly for design companies not directly involved with manufacture. Additionally, the IDA permits the capture of company knowledge and IP in the processes used by human experts to relate design to manufacture and remains an important manifestation of that knowledge after the experts leave the company. Development of manufacturing knowledge sources is continuing, with assistance from academic and industry sources, together with a selection of broad domain feature recognition algorithms to support manufacturing evaluation. The selection of a Decision Support System is yet to be made, however a number of options are available for solving complex problems like those inherent in the 'fuzzy' nature of design shape and manufacture evaluation. The complexity of this problem may be extended to include concepts like minimum weight or minimum tolerance in addition to satisfying functional and economic criteria. As a first step, case-based reasoning or rule-based approaches will be tested in preference to a more complex solution technique, for reasons of programming simplicity. The acceptance of a design aid for manufacturing can be foreseen when it minimizes disruption to the creative design process by being suitably time responsive to the requirements of the user. Thus, the technology that will be selected will be focused on this objective.

Conclusions

Commercial pressure within the global aerospace industry to reduce non-recurring engineering design costs has necessitated the integration of design with downstream applications like manufacturing process planning, analysis, assembly and inspection. Feature recognition is a process for identifying and extracting design features from a geometric CAD product model and may be used as the basis for developing KBE tools to automate the integration of design with downstream processes. The use of neutral file formats like IGES and STEP provides marshalling of the geometry components used to create a part, and thus makes the model independent of the parent CAD program and the CAD operator's hierarchy of design features used to build the product shape. When combined with a wireframe model, this design feature independence is a useful method of supporting generic feature recognition processes, particularly those not developed for application in a specific manufacturing domain. Feature recognition, as a core component of an Intelligent Design Advisor (IDA) for supporting the conceptual phase of engineering design has the potential to further reduce design cycle time within the framework of concurrent engineering. An IDA capable of rapidly establishing an optimum manufacturing solution based on initial product geometry can support designers of engineering products, while retaining and re-applying company knowledge and intellectual property.

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