Expert systems for integrated material/part/process design in polymer composites. A task specific problem solving approach.
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ABSTRACT

Polymer composites provide the opportunity to design the material as well as the part. The domain for composites design can be viewed along three dimensions, namely material design, part design and process design. These dimensions are not independent and their interactions provide important decision points that impact manufacturing. Integrating material, part and process design becomes increasingly important as composite materials penetrate the durable goods markets and as traditional markets, like aerospace, become more cost conscious. To address these challenges, a suite of expert systems for integrated material/part/process design is being developed.

These expert systems were designed and implemented using the Generic Task Theory. Task specific approaches, like Generic Task Theory, focus on the high level problem solving goals, knowledge structuring and inference strategies of a problem solver and not on the implementation details (rules, frames or objects). The paper discusses two prototypes that were designed and constructed using this task specific viewpoint. These include an expert system for composite material design and an expert system for composite fabrication selection.
INTRODUCTION

Polymer composites provide the opportunity to design the material as well as the part. The domain for composites design can be viewed along three dimensions, namely material design, part design and process design. These dimensions are not independent and their interactions provide important decision points that impact manufacturing. Integrating material, part and process design becomes increasingly important as composite materials penetrate the durable goods markets and as traditional markets, like aerospace, become more cost conscious. The goal is to bring to bear the necessary decision making knowledge at important points in design procedures. To address these challenges, a suite of expert systems for integrated material/part/process design is being developed.

Material design involves the mapping from requirements (mechanical, thermal, optical, electrical and chemical) to choices of fiber, polymer matrix, chemical agents and processing conditions. In part design, requirements include partial geometric information, tolerances and loadings (mechanical, thermal and vibrational). Part design determines the overall part geometry as well as the fiber architecture, fiber fraction, orientation, stacking, integration of other materials (honeycomb and/or foam) and issues of bonding and fastening. Process design involves an array of complex problem solving activities, some of which can be viewed as process technology selection.

This paper discusses the continuing development of two prototype expert systems: CTechSel (Composite Technology Selector) and CMatDesign (Composite Material Designer). CTechSel provides assessments of polymer composite fabrication technologies based on qualitative economic factors and information about the composite part. CMatDesign generates a family of composite material designs based on performance and environmental factors. Each of these prototypes were designed and implemented using the Generic Task Theory of expert systems. Task specific approaches, like Generic Task Theory, focus on the high level problem solving goals, knowledge structuring and inference strategies of a problem solver and not on the implementation details like rules, frames or objects.

EXPERT SYSTEMS TECHNOLOGY

Expert systems are a technology whose goal is the explicit computational representation of problem solving. Problem solving is viewed as a combination of knowledge needed for the activity at hand and the inference procedures performed on that knowledge in the service of problem solving.
goals. The problem solving captured in an expert system could be related to engineering practice and experience. The problem solving could also be related to engineering fundamentals and first principles. An explicit computational representation allows aspects of problem solving to be encoded as computer programs.

As design aids, expert systems can provide a number of services. For example, they can be used to capture knowledge and inference related to routine engineering tasks, freeing design engineers for more creative efforts. Additionally, expert systems can increase the access of problem solving knowledge to other design engineers, many of whom might be less experienced. For experienced design engineers, expert systems can provide focus for problem solving, criticism of current designs and suggestions for design adaptations. By explicitly representing the knowledge and problem solving inferences important for design, expert systems act as a medium for transferring expertise, thus enhancing opportunities for education, technology transfer and training.

Our research effort in expert systems has focused on the development and application of task specific architectures in the context of Generic Task Theory [1]. Much of the work in expert systems focuses on implementation details and discusses problem solving systems in terms of rules or frames or objects. The task specific approach encompassed in Generic Task Theory attempts to describe expert systems at a higher level, namely, at the level of information processing tasks that perform problem solving. At the task level the emphasis is on the structuring of knowledge and how that knowledge is used in problem solving. The task specific approach to expert systems provides knowledge representation templates and a selection of specialized problem solving inferences matched to a particular problem solving activity. The theory also supports the construction of specialized programming languages (sometimes referred to as task specific languages) that help facilitate the construction of expert problem solving systems.

INTEGRATING MATERIAL, PART, PROCESS DESIGN

Conceptualizing the domain of composites design along the dimensions of material design, part design and process design allows a decomposition of the problem solving activities as shown by the grey axes in Figure 1. It is important to point out, however, that the considerations of material, part and process are intimately tangled and not seamlessly separated. Success in design takes into account these interactions and automation of design problem solving must do the same if it is to be successful. Not taking into account these
interactions contributes to the failings of many polymer composites efforts.

Our current implementation includes aspects of material design (CMatDesign) and elementary process design in the form of process technology selection (CTechSel). These are represented in Figure 1 by the solid black arrows. CMatDesign generates a family of composite systems from material requirements concerning the performance characteristics and environmental conditions the material is expected to face. CTechSel produces a set of suitable composite fabrication methods (liquid molding, pultrusion, etc.) based on processing issues like throughput, part uniformity and part shape complexity. The knowledge sources for each of these prototypes are the common composites literature [2, 3] as well as discussions with domain experts. Currently there is no prototype system for part design. The issues surrounding part design have been parameterized and serve as inputs to the current problem solvers for material design and fabrication selection. A conceptual architecture for part design is currently underway and is discussed elsewhere [4].

THE MATERIAL DESIGNER

The development and evolution of the material designer, CMatDesign, is discussed in detail elsewhere [4, 5]. This problem solver makes use of the task specific architecture known as routine design [6]. Routine design is based upon two fundamental characteristics that should exist in the application domain. First, the problem solving to be captured in the expert system has
been done many times before, each time with different but similar requirements, until knowledge is available in a form that allows efficient solution of the problem. Second, the design proceeds with each sub-problem selecting from a previously known set of well-understood alternatives. These two features exist in the domain of composite material design.

Being part of Generic Task Theory, routine design offers a host of knowledge templates or constructs for building a design problem solver. The type of knowledge constructs available in routine design include: specialists, selectors, sponsors, plans, tasks and steps. The major organizing structure in routine design is the specialist. Metaphorically, the specialist construct offers a collection of expertise or knowledge on how to complete a portion of the design problem. The specialist organization is hierarchical, implying that the design problem is completely or nearly decomposable into appropriate sub-problems. The arrangement of the specialist will depend on the regularities that exist in a particular domain.

The design inputs for CMatDesign include the application type, resistance to corrosion, humidity & flame, rigidity, tensile modulus, use temperature and glass transition temperature. These input features are binary valued, continuous valued, or select one from a list of values. The design output is a composite system of polymer matrix, fiber material, chemical agents, cure time & temperature and post cure time & temperature.

Engineering problems rarely have a single solution. In most cases, several composite material systems might satisfy the performance characteristics. In its initial form, the routine design paradigm supplies a single design that satisfies the performance characteristics. Based on our discussions with various industrial representatives, the output of a family of designs presents a more effective aid to composite designers. These issues required a modification of the routine design paradigm to produce a family of designs instead of a single design. CMatDesign uses this expanded paradigm and generates a family of polymer composite material designs.

PROCESS DESIGN - SELECTION OF FABRICATION TECHNOLOGIES

Although the ultimate production of a composite part depends on a host of economic factors, the selection of potential fabrication technologies can be based on technical arguments and abstracted economic factors instead of detailed economic models. In this way the composite designer is presented with a family of composite systems based on technical considerations (e.g. performance and use environment) and a set of potential fabrication
technologies based on largely technical issues and some economics. With this in hand the design engineer can then apply a more detailed economic model for final evaluation. The goal here is not to reject any technically feasible designs because of some assumptions in a particular economic model. The detailed economic screening can come after the procedures that make use of the expert system.

The expert system for technology selection, CTechSel, uses 14 input factors to evaluate eight fabrication technologies. The eight technologies are: pultrusion, liquid molding, filament winding, spray-up, sheet molding, hand layup with room temperature cure, prepreg layup with autoclave cure and autotape layup with autoclave cure. The 14 inputs include a number of qualitative economic factors (e.g. throughput and material waste) as well as information about the part (e.g. size, geometric complexity and hybrid nature). As output, CTechSel assigns each fabrication technology with a qualitative confidence value measuring how well that technology matches the processing concerns input by the user.

CTechSel makes use of two Generic Task problem solving architectures for this selection problem [1]. The first involves using structured pattern matching. An alternative approach, combines structured pattern matching and hierarchical classification. Using structured pattern matching alone would involve constructing detailed match tables for each fabrication technology. Some or all of the 14 features would be used as evidence to support or oppose the use of a particular fabrication technology. Patterns of potential feature values would be preenumerated and map to qualitative confidence values (strongly match, match, weakly match, neutral, weakly against, against, strongly against).

Often among such a collection of related items (like composite fabrication technologies), there will be common features used to evaluate suitability. The existence of common features and the opportunity to cluster or group items together in abstract categories facilitates the application of hierarchical classification. In hierarchical classification items are organized as categories of related concepts. The concepts are organized in a top down fashion from most general concepts to most specific concepts. Instead of evaluating fabrication technologies one by one, the hierarchy is examined in a top down fashion. Each concept contains evaluation knowledge in the form of a structured pattern matching table. The number of features and the number of patterns in these tables would be expected to be fewer than in the case where structured matching alone is used.
SOFTWARE ARCHITECTURE

The Generic Task Theory supports the construction of specialized tools for constructing specific types of expert systems. These tools can be thought of as specialized role-limited programming languages. The constructs available in these languages match the descriptions of the problem solving at the task level. The software architecture for the material designer is shown in Figure 2.

The top layer is the expert system for material design. The next layer is the tool for building a particular type of expert system, in this case a routine designer that generates multiple designs. The tool is named MDSPL after its predecessor DSPL. The final two layers are implementation specific. At the bottom is the implementation language, which currently in our case is SmallTalk. Just above the SmallTalk layer is a layer that contains constructs for building Generic Task-based expert system tools. SmallTalk was chosen as the base layer because of its general portability across software and hardware platforms. SmallTalk also supports a completely portable interface to the user and developer. Other languages have been used as the implementation layer in the past including LISP, OPS5 and G2.

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Figure 2: The Software Architecture

There are several advantages to this layered architecture. A person using the expert system need not be aware of the layers below. Additionally, the developer of the expert system, by having access to a task specific tool, need not understand the lower level implementation languages (in this case SmallTalk). CTechSel makes use of the same layered architecture approach, however a different tool is used for its construction since CTechSel represents a different information processing task.
SUMMARY AND CONCLUSIONS

This paper has explored the issues surrounding the design of composite materials, composite parts and composite fabrication processes. Prototype expert systems for material design and for composite fabrication technology selection were discussed. These prototypes were developed under the Generic Task Theory for expert systems. The use of the Generic Task approach facilitated the design and construction of these prototypes with its focus on high-level issues and the use of task specific tools. Problem solving related to polymer composites and design remains a fertile area for expert systems applications.

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