RAPID PROTOTYPING DECISION SUPPORT SYSTEM

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Abstract

An application has been produced to rate Rapid Prototyping system suitability based on designer requirements. The software is part of a project to produce a comprehensive Design For Rapid Prototyping (DFRP) methodology. Using a combination of database searches and user-defined weighted rating, the system uses various design requirements to make qualitative suitability decisions. MS Visual Basic has been used to implement a user-interface to manipulate an MS Access database. Proposed features include system validation achieved by designers' feedback on prototype performance. This will help to remove the false expectations sometimes associated with RP and will ultimately promote its wider usage.

Introduction

Rapid Prototyping (RP) is a revolution in manufacturing technology. The use of RP can significantly reduce manufacturing lead-time, lower product development costs and produce better quality products. It is not surprising that the RP industry continues to grow rapidly[1]. To fully maximise the benefits of RP, there are several factors which require consideration. These include firstly the decision of whether the use of RP is appropriate. If this is confirmed, the designer is faced with an array of RP processes and materials from which to select.

Currently, the decisions regarding which RP process, machine and material are dependant on the company's in-house facilities or made by the Service Bureaux (SB). A tool which aids this decision making process offers designers a wider choice when selecting an SB. If the designer is able to determine the most appropriate RP combination, then the constraints of a certain SB do not apply and the prototype is likely to satisfy its requirements more closely. In order to make such a decision, designers require access to data relating to all prospective alternatives which optimises the effective use of RP. With the continual introduction of improved RP technologies and systems, current performance levels are very difficult to assess. Consequently, there is a requirement for an expandable system capable of accommodating the advances made within the field of RP. It would inform designers of the different RP systems available and the typical results to expect.

The ultimate goal of producing a Rapid Prototyping Decision Support System (RPDSS) is to enable RP to be used to its full potential throughout a project's duration, maximising all the associated time-to-market, cost reductions and quality benefits. A fully functional RPDSS would be able to accept CAD data and through its analysis, determine firstly whether the use of RP is appropriate, and subsequently to decide which process, machine, material and RP specific parameters (such as part orientation) to use. The long-term project aim is for the software to apply analysis directly to the CAD data to determine RP suitability, with little or no designer interaction. Achieving this goal is dependant on many factors; one such factor is that the design requirements such as tolerances and surface finishes be represented by the CAD model, achievable by using feature based design[2]. A complete RPDSS capable of achieving the proposed functions will only be achieved through development of a standard format for representing such design requirements.

Software Requirements

The ultimate project aim was therefore to design and produce a design tool which would suggest the optimal RP system and material for a variety of processes using desired or inherent prototype attributes. The core software function is to suggest the optimal RP system and material for a variety of RP processes based on prototype attributes and designer requirements. The software was developed to operate through a user-friendly interface requiring little or no prior RP knowledge. To enable the expansion into a complete RPDSS, the software produced includes a universal shell and database structure into which the other RPDSS modules may be placed. The software also requires the ability to learn via designer feedback of prototype satisfaction enabling the continual improvement of output.

The core prototype attributes (1-3) and requirements (4-9) specified by the designer and used to determine the suitability were selected to be:

1. Quantity
2. Timescale
3. Budget
4. Dimensions
5. Function
6. Features
7. Accuracy
8. Strength
9. Surface Finish
10. Machinability

Computer-aided RP selection systems are not a completely new concept but have tended to focus on one specific RP process [3-7]. With the numerous RP alternatives now offered by SBs it was considered much more useful to model several of the available RP processes. Based on their degree of industrial presence and availability of data, the RP processes selected for comparison were:

- Fused Deposition Modelling
- Laminated Object Manufacture
- Selective Laser Sintering
- Solid Ground Curing
- Stereolithography

An important consideration in selecting the suitability evaluation method was to be aware of possible system improvements, potential data structural changes and the modelling of subjective data. The advantages of relational databases lie in the high degree of flexibility regarding subsequent modifications of the data structure. The use of weighted rating in conjunction with a database offers the advantage of combining subjective measure modelling with real data and was therefore chosen as the processing method to determine system suitability.

This project concerns the pairing of design requirements and RP machine capabilities and the subsequent quantification of suitability. Calculating the degree of coalescence is highly dependant on the data concerned. The data used by the software can be categorised into design requirements (specified by the designer) or RP capabilities (determined by benchmarks/manufacturer specifications). With respect to suitability evaluation, each data item can be further classified as either static or dynamic. Part size is one such example of a static data item and is of no relevance unless it exceeds the capacity of the RP machine. There exists no conformance measure that can be made as to how well a machine can accommodate a prototype of a certain size; it either can or cannot.

Using static data alone will only provide Boolean constraints upon suitability without indicating its degree. Nevertheless, static data must be modelled into the system since it will be meaningless to provide a solution which fails to meet the constraining factors, regardless of how well it may meet the more dynamic requirements. Dynamic data items are therefore of much greater interest since they can be used to represent measures of system suitability, i.e. how well a system is suited to a particular application when compared to another.

Suitability Calculation

Suitability is the ratio between design requirement and machine capability. For a prototype budget requirement of £2,000, a certain machine is 100% suitable with respect to budget satisfaction if the prototype it produces costs £2,000; following this, the suitability is then 50% if costing £4,000. The percentage suitability for a specific requirement can be formulated as shown in Equation 1:

$$\text{Percentage Suitability} = \frac{\text{Design Requirement}}{\text{Capability}} \times 100 \qquad (1)$$

There are some constraints over the use of Equation 1. Using the above example, if the prototype price (Capability) is £1,000 it cannot be said that the suitability is 200%. This formula also only applies when a low level of capability is superior. This is true for accuracy, surface finish, build-time and cost. For strength and machinability the formula requires inversion.

Weighted rating states the suitability rating be multiplied by the importance value of that attribute. However, in doing so the problem arises that a high specification prototype with corresponding importance values will perform disproportionately when compared to a less important prototype. To remedy these discrepancies, before weighting the individual suitability ratings, the importance values must be levelled. This can be formulated by Equation 2:

$$\text{Levelled Importance} = \frac{\text{Importance Value}}{\sum \text{Importance Values}} \qquad (2)$$

The possible numeric values associated with the importance specified by the designer were given consideration and the most logical system was found to be a five level system. The lowest level of importance, 'Irrelevant' implies that the design requirement is not considered by the designer to bare any relevance to the prototype's conformance to specification. The suitability for a requirement determined irrelevant automatically receives a suitability rating of 100% although this score is not used in the aggregation of the overall suitability.

At the other extreme, it was considered necessary to provide the option for 'knock-out' importance criteria to be specified. Selecting the importance level, 'Mandatory' for any factor will ignore any system which fails to satisfy the specific design requirement irrespective of other suitability rating, and thus immediately giving the system a suitability rating of 0%. Clearly, this importance level should be used with care or very few systems will be considered, however, having the option to place a very demanding requirement upon it was considered appropriate as the situation may arise in industrial situations. For example, if the part is to be stressed to at least 20MPa, a system offering an RP solution incapable of satisfying this constraint will render the system invalid for such occurrences.

Intermediate levels of importance 'Unimportant', 'Desirable' and 'Important' were chosen to provide the weighting schema each with increasing associated importance values. Naturally, for multiplication purposes these levels require quantification. The importance values using the scale; Important: 3, Desirable: 2 and Unimportant: 1 have been totalled, and each value divided by this total, giving a levelled importance for each factor. The overall system suitability can therefore be formulated by Equation 3:

$$\text{Total Suitability} = \sum\left(\frac{\text{Design requirement}}{\text{Capability}} \times \left(\frac{\text{Importance Value}}{\sum \text{Importance Values}}\right)\right) \qquad (3)$$

Software Implementation

The design requirements are input via a form-filling method programmed using MS Visual Basic 4.0. indicated in Figure 1.

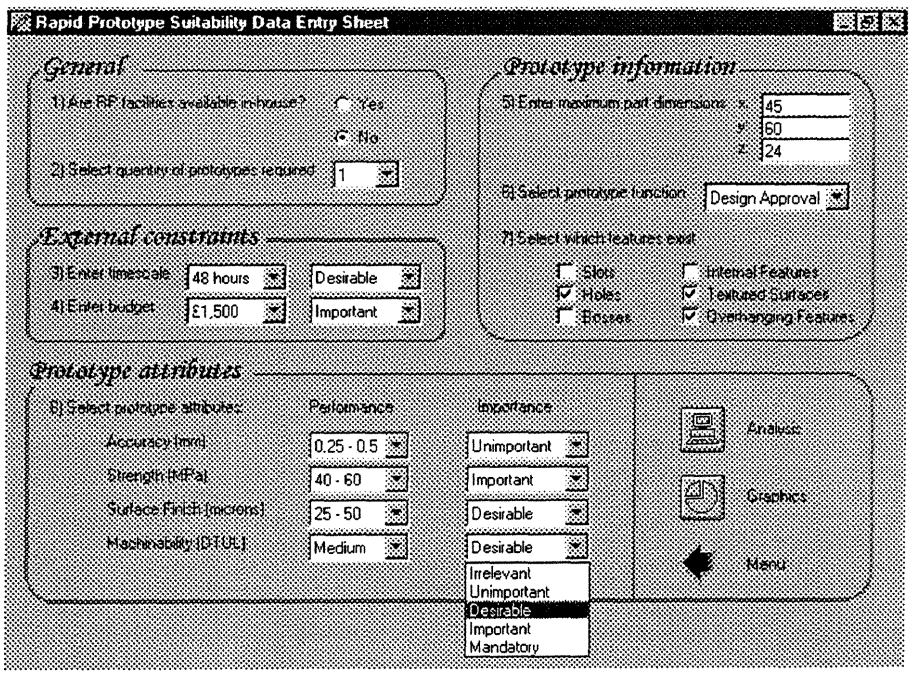

Figure 1: RPDSS suitability requirements entry screen

The form uses a series of drop-down boxes giving a selection of pre-defined options. Once the requirements have been entered, the analysis is performed following Figure 2. The boxes to left of the diagram indicate table names within the database where the relevant data is stored and the labelled lines indicate the data flow.

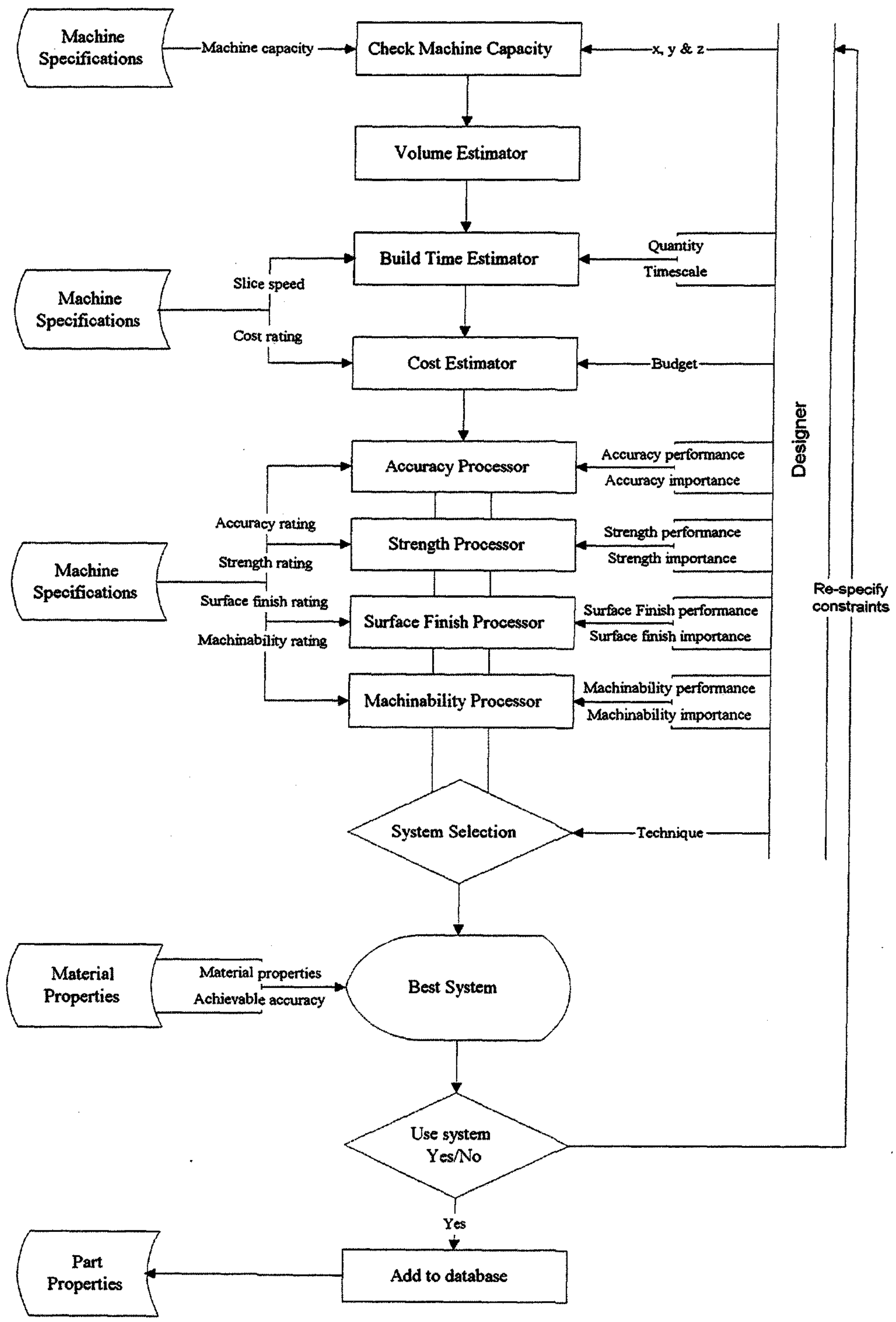

Figure 2: Flowchart for suitability procedure

The subsequent analysis is presented to the designer with a list of suitability percentages, highlighting the most superior process (see Figure 3). For the suggested process, the most suitable machine and material is detailed. Specific material properties may then be viewed, as can the best machine and material for other processes. The RP data stored within the database has been collected via an extensive literature search and manufacturers' specifications.

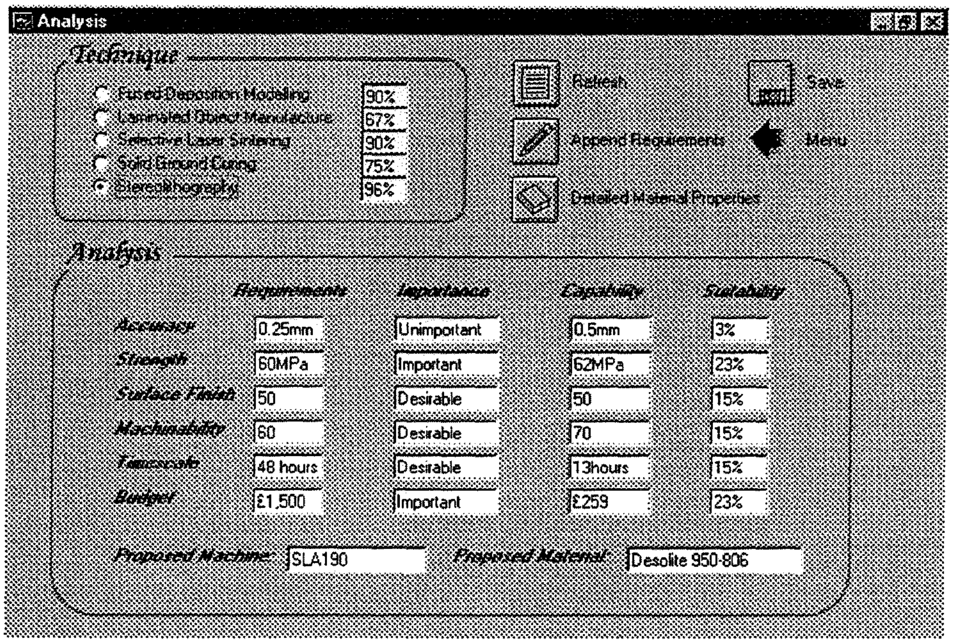

Figure 3: RPDSS analysis screen

Validation Case Study - Fan Development Scenario

The prototype attributes and requirements were selected based on the requirements of a industrial fan. Since the case study selected for implementation did not include all the data required, it was necessary to make occasional assumptions (see Table 1).

Characteristic	Value	Characteristic	Value
In-house facilities	No	Accuracy required	0.5mm*
Quantity	12	Accuracy importance	Important*
Length	150mm	Strength required	30MPa
Function	Functional testing	Strength importance	Desirable
Timescale	< 5 weeks	Surface finish required	20 microns*
Timescale importance	Important	Surface finish importance	Desirable
Budget	£2,000*	Machinability required	N/A
Budget importance	Important	Machinability importance	Irrelevant
Accuracy required	0.5mm*		

* indicates assumed data

Table 1: Fan design requirements

After data entry, the software performed the analysis. The suggestions produced by the software are summarised in Table 2, listed in order of suitability. This was a highly successful test of the software since LOM was highlighted as the most appropriate method, the same process used by ABB Fläkt Industri AB, Sweden[8]. The software also gives a relatively high level of suitability which is agreement with the satisfaction expressed. The analysis showed not only consistency between software recommendations and real-life applications but also indicated areas where different RP solutions may have provided more satisfactory results[9].

Process	System	Material	Suitability
Laminated Object Manufacture	LOM 2030	Bleached kraft paper	94%
Fused Deposition Modelling	FDM 1500	Plastic P301	92%
Stereolithography	SLA 500	EXactomer 5201 AR	90%
Selective Laser Sintering	Sinterstation 2000	LN 4010	87%
Solid Ground Curing	3D Modeler	Solimer G-5601	86%

Table 2: Summary of software results

Future Work

Several areas have been identified for further work which include improved build-time and cost estimation modules. Research at the University of Nottingham is examining the use of neural networks in conjunction with an RP model database to enhance these such modules. There is also the possibility for the development of an RPDSS internet web-site. This would enable world-wide usage of the software, access to the RP capability database and provide the means for user feedback.

More design scenarios should be applied to test the software validity and identify its weaknesses. These weaknesses exist largely due to lack of RP database entries. Software development is to continue with the integration between the RPDSS and CAD. This is intended to enable direct analysis of the CAD model to determine RP suitability with less designer interaction. This is only possible through the use of feature-based design and a CAD model format capable of representing all prototype requirements[10].

Conclusions

This project has established a framework for an RPDSS and produced a user interface for its implementation. The RPDSS module relating to evaluating the suitability of different RP machines has been the main area of development. This has been conceived, designed and implemented to evaluate the suitability percentages for several combinations of RP machine and material and to display the suitability ratings for five major RP processes. There are several potential benefits of using such a system:

- Higher level of designer productivity
- Improved access to RP data
- Promotion of RP

It is hoped that this development work will be furthered by future projects and that the goal of producing a fully functional RPDSS is achieved.

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