Knowledge representation for cost estimation at the design stage for textile printing products

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Abstract - Textile and garments is a highly dynamic industrial sector, in terms of frequency of product renewal and new product introduction. In recent years the evolution of technological tools has improved the design efficiency in two ways: first, designs tools as 2-D 3-D CAD systems to allow trim in a more accurate way the final product features and cost. Second tools to store and manage information through the whole product development life-cycle in a formal way. Costing is one of the most important activities to make product decisions. Against traditional estimation methods that could be applied until the technical description of the product is completed, new methods exist which allow to estimate the cost quickly and with an acceptable accuracy. This paper proposes methodology based in a hybrid neuro-fuzzy model which allows to recover and represent design knowledge to cost estimate in these kind of dynamics environments.

Keywords: Cost estimation, neuro-fuzzy, knowledge representation

1. INTRODUCTION

A major challenge for clothing producers, has faced the end of international apparel quotas last December 31 2004, is to improve the interactions between the production centres and designers. The most important goal in that sense is to reduce the product development cycle time by making more efficient decisions at the early design stage (Senanayake et al, 2001)(Kahn, 2004)(Kilduff, 2000). One of the most important criteria to validate a product is the total cost. This cost must include even the raw materials, manufacturing and transportation cost, but a capital constraint is that at that stage the product is not completely defined and the traditional analytical costing systems cannot be used.

Due to the cost of increased product complexity and shorter lead times, for the textile and garment producers it is becoming more and more difficult to provide an accurate quotation price to the client. If they are forced to provide a quoted price quickly, they may find that this price may not be profitable after confirmation.

As mentions (Roser et al., 2003) the designers often find that they are confident about the performance of some design alternatives and uncertain about others. Similarly, alternative design changes may differ substantially in uncertainty, potential impact, and cost. Current practice of the designers is to spend an enormous amount of time to review new products, and after the product is finished, to see if they can trim cost. At this early stage, decisions about materials, dimensions, surface, touch of textile and production methods have to be made. Since all factors are inter-dependent to each other, lowering the cost of one aspect may increase the cost of another. For instance, the selection of a less expensive material may require extra operation steps in order to achieve a target colour or quality level. Several of these factors are known but not all. Very often, from the designers point of view, colour intensity or design complexity do not influent cost directly, therefore they do not include design complexity to estimate cost. A way to solve this problem is to use cost information from the past products. Using these data allows us to develop fast and accurate estimation tools during the design stage, where technical descriptions of a product and the possible production plans are not known or completely decided.

In recent years, several technological solutions have been developed as PDM or PLM (Product Data Management or Product Lifecycle Management). These kind of tools give opportunities to manage and store information during the whole product development cycle. In [5] a survey on enterprises owners of the several PDM systems on the market, shows that most of then are using this tool to costing products at the development stage in addition to the other PDM functionalities. However, the most recurrent drawback mentioned, to achieved this task are the complexity of utilization, the need of highly detailed information, that would require too much extra work for users, also the heterogeneous methods to compute cost and the number and diversity of users (Desmarteau, 2002). The main goal of this paper is to propose a way to take advantage of the nowadays available information during the product development process, in order to use simplified methods to obtain easy but accurate cost estimates at the first stage of the product lifecycle.

From conceptual design to Production Plan

The product development cycle (figure 1), defined in (Senanayake et al. 2001) as the time elapsed, between designer's concept and, the moment when the style is released for production. Their analysis shows that as the number collections increase, and the diversity of most products line expand, the need to shorten the time required to develop new products becomes more important. Some studies measured the typical product development cycle time for fashion garments in a range between one to three months, with several trial until the right product is reached. In [2], on the enterprise's opinion to be competitive this time remains too long to follow the market dynamics.

In practice the first cost estimation occurs at the end of the prototyping step, when we have all product details. That means that all the previous steps of the cycle must be accomplished before the first estimation and that for any change because of cost, each of all the previous steps must be reviewed. This dysfunction is determined by two main reasons,

- First, the difficulty to store and manage product information at the development stage because of the high product diversity, the interdisciplinarity of the people involved in the process and the kind of information to be managed.

- Second, as the most current practice to estimate product cost is based only in raw materials and production time consumption defined by the production plan, particularly for garments, it is difficult to establish correlations between decisions at conceptual stage and the time spent by each individual operation of the production plan.

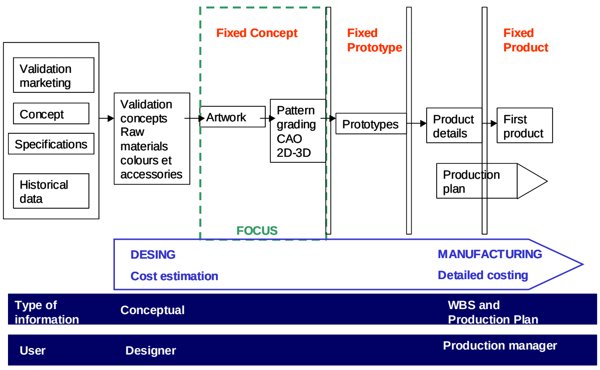

Figure 1. Product development cycle activities

In the next future better integration between designers and manufacturers could be achieved, and these two constraints solved through the application and generalisation of two emerging technologies for the textile and garment industry: the PDM systems and Cost estimation.

Product Data Management systems (PDM)

Since early 90's, PDM tools started to be applied in the textile and garment industries as a answer to the necessity to integrate the information created through the product development process. A PDM system is a common place incorporating product information coming from the processes described figure 1: conceptual styles, grading and pattern, suppliers, prototypes and pre-production processes, this integration of diversified information (graphic, descriptive and numeric) allows these tools to have several useful functionalities in order to improve the management of the product development process through:

– The sequential integration of the product data at each development step to consolidate a final product.
– A holistic vision of the development process in order to follow product modifications and improvements, time to accomplishment and the person in charge for each step of the process.
– Possibility to improve communication flow and formalisation, inside the company with all concerned departments and externally with suppliers and customers which means better collaboration.
– To share data with Enterprise Resource Planning (ERP) systems and commercial and marketing tools.
– To stock all the product historical information in order to estimate cost for future products.

The above considerations mean that, the first dysfunctions is been gradually solved by the PDM dissemination. However, all this volume of information makes complex the interaction with these kinds of tools and some users say that because of that, they are not using all functionalities of the PDM systems. A simplification process must be carried out in order to give more flexibility to the available systems on the market, and to improve make decisions during the whole product development cycle.

Parametric Cost estimation

The cost estimation techniques have been improved and applied in several industrial fields, as automotive, aeronautical or spatial. Their accuracy and flexibility allows to make cost estimation since early stages of the product life cycle. The basis of this approach is to establish correlations of the product designer decisions and their economical implications, taking as basis the historical case base, and the available knowledge. Again in figure 1, that means that we can establish a cost estimation model at a early stage as conceptual design or the pre-production stage and also for each intermediary stage. A Cost estimation tool is composed of a series of Cost Estimation Relationships (CER), ground rules, assumptions, relationships, variables and constants that describe and define a specific situation. And the CER is a mathematical expression, giving cost as a function of one or more cost driver variables. The main advantages in using CER are:

- It allows the user to provide quick estimates without a great deal of detailed information.
- Since the CER's are based on actual product cost history, they reflect impacts on cost growth, schedule changes, and conceptual or engineering changes.
- The possibility to make relations cost-to-cost (ex : production time, raw material and cost) and relation cost-to-noncost (ex : design patterns, product complexity, product range and cost)
- Although these methods usable during the whole life cycle, some are better than others depending on the context. For instance, the application of analytical, as a complementary method, is that future cost can be predicted with a great deal of accuracy.
- A better comprehension of the system to be modeled by extracting knowledge from the data base to be interpretated.

Benefits of Quick Costing and Pricing

In a highly complex supply chain as textile and apparel, the reduction of the development product life cycle and cost pass through combination of a real collaboration between designers and manufacturers, and also the enhancement of tools in order to facilitate this collaboration [8]. The introduction of the product information management and their improvement by using new technologies tools as the cost estimation, will lead several impacts in order to minimize the wasted time in the product design and manufacturing process. More exactly, the methodology proposed in this paper will improve the textile product development process by:

- The improvement of the designer visibility, in order to have a better perception of the economical implication of his decisions taking into account the functional, aesthetical and structural parameters.
- A better communication quality between the designer (Stylist or Engineer) with the production process and the supply chain partners.
- The possibility of integration of aesthetical features as cost drivers that could act as a resource for designers.
- Product development and validation time reduction in order to make better and faster customer response.

These kind of universal function approximation property gave encouragement for finding increasingly better models but also recognizing that there was a limit depending on the structural elements used and their application field. In other, as mentioned in [11], the way as the interactions between soft and hard cost drivers of the product must be studied.

2. FUZZY LOGIC AND COST MODELLLING

Fuzzy logic is a technique that models vagueness, ambiguity and imprecision, and enables complex systems with many parameters to be effectively modelled using principally expert knowledge but can also take advantage of 'learning' from input output data pairs to improve the approximation (Zadeh, 1972). Previous research has shown that against the other modelling techniques, the hybrid neuro-fuzzy models provide the combination of strengths of both fuzzy and neural networks models by avoiding their weaknesses (Gray *et al*., 1997). Thus the main feature is an adaptive system able at the same time to extract rules and knowledge from historical data bases and express it in a comprehensive way through linguistic rules, to be easily understood and applied by product designers. This approach allows a more efficient treatment of the inputs, to reduce the number of rules needed and to obtain a more clear and interpretable output response surface. In addition to accuracy, these properties are the most relevant for our specific model.

The central part of our work is to apply fuzzy rule induction methods to improve the interpretation of cost models. In order to simplify the set of rules resulting in the last model, the clustering techniques seem to be effective, especially for data bases with high number of variables or scarce cases.

2.1 Hybrid Neuro Fuzzy Cost Estimation Model

We use the well known model named Adaptive Network Based Fuzzy Interference System, (ANFIS) (Jang, 1993). The learning process builds a model connecting input variables with typically one output variable, using a set of rules. The process of fuzzification builds a certain number of fuzzy sets represented by membership functions for each variable. The inference system uses these fuzzy sets and the rules to build an output value which will be translated into real number ("defuzzified").

The ANFIS use a hybrid-learning algorithm in order to identify the fuzzy sets by using the following steps.

- Fuzzification and rule identification: we use the sub-clustering method as mentioned in (Chiu, 1994), in order to identify the inputs of the fuzzy model. It allows building input-output functions, under the form of IF-THEN sentences.

- Training: to the training step optimises the parameters in the ANFIS model which has been generated by the previous step. In order to avoid the overfitting problem, the early stopping technique was used, by minimising the estimation gap between the training and test data set, as shows the figure. 1. The estimation score of this model is on the recapitulative table.

2.2 Simplified Hybrid Neuro Fuzzy Cost Estimation Model

In order to simplify the set of rules resulting in the last model, the clustering techniques seem to be effective, especially for largest data bases or scarce cases. Many authors have studied the problem of the model simplification and the equilibrium between an accurate and an interpretable model (Guillaume *et al.,* 2001, Casillas *et al*., 2003). According to (Guillaume *et al.,* 2001, there are three main conditions to drive the rules set interpretable:

- The partitions must be legible to the experts; the membership functions must be linguistic terms, related with the system in order to make the rules comparable.
- The number of rules must be minimal. This rule simplification will drive less accurate models, but improve their robustness and their generalisation capability.
- The rules must be defined only by the more influent variables.

Then we decided to simplify the previous ANFIS model, by developing a method which is composed by two main actions: the first simplification concerns the reduction of the number of Membership Functions (MF), represented by μ_i. The basis used is the aggregation of several MFs in a representative MF through a distance notion $\Delta(i, j)$ between two MFs i and j. The pair (i, j) is chosen by running an accuracy test for the remaining MFs set. The distance is defined as:

$$\Delta(i, j) = \int_{-\infty}^{+\infty} \left|\mu_i(x) - \mu_j(x)\right| \cdot dx \qquad (1)$$

The second step looks for the simplification of the rules in the ANFIS model. The basis here is the search of a rule set satisfying a performance criterion previously defined, in this case the root means squared error (RMSE), and iteratively running the algorithm until we find the most accurate and interpretable rule set.

3. APPLICATION EXAMPLE IN THE TEXTILE FIELD

The design processes in textile printing follows a chronological sequence of steps, starting with the concept design to product process plan definition. Thus this dynamic process starts with a set of ideas proposed by the designer that are classified by a complex evaluation system before the product arrives to the market as well explained in (Moxey *et al*., 2000). The first designer inspiration sources are for example, the intent to create new forms or the use of elements, coming from the social or natural environment. At this stage the designer decisions depending mainly on the next factors:

Aesthetical factors: colour, texture, brightness, touch, and pattern
Functional factors: isolation, chemical resistance, heat transfer and dissipation etc.
Commercial factors: delay, quality and price.

The classical idea is that the designers make choices based only on aesthetical parameters. But in practice the product definition process takes into account the economical and functional constraints. For a designer the paradigm of aesthetic conventions that determine creative solutions within printed fabric design are constrained by technological and market factors. The creative design must be new related to the previous collections and must be validated by the members of the system.

For the specific case of the textile printing industry, we have carried a research study about the process of selecting design. The results show it is highly speculative and could take and the financial investment is extremely high in comparison to the potential product commercial success. Unfortunately, all the esthetical paradigms and customer requirements are explicit only in part until the product freeze point, when a lot of time has passed it could take between three and four months. Thus makes very important to have reliable economical evaluation of the product changes in the phase when the product is being defined. For the manufacturers in that kind of highly dynamic environment the product development implies to react as soon as possible to customer requirements and at the same time to optimise the capital investment.

In fact, the product total cost depends on several components related to the direct and indirect cost. The time and resources spent in the product development process, the technological capabilities (production infrastructure, human knowledge and skills) and of course the product features. The combination of those factors results in a specific product cost.

A theoretical analysis of the actual cost components and the main design decisions were analysed. By using a principal component analysis technique (PCA), we found that most of the decisions taken in the design stage are related to four main variables. X1 product style, original designs with a focus on a specific theme, X2 base cloth colour options, X3 design colour options, X4 expected amount of production. As for the experts in printing textile industry the product complexity was related to number of design colours.

4. EXPERIMENTAL RESULTS

Following an experimental research and the considerations in (Moxey *et al*., 2000) for the textile printing industry, we have treated a database in order to obtain an accurate cost model but more easily interpretable than models obtained from others modeling techniques. In the textile industry unfortunately, all the esthetical paradigms and customer requirements are explicit only in part until the product freeze point, when a lot of time has passed it could take between three and four months. Thus make very important to have reliable economical evaluation of the product changes in the phase when the product is been defined. For the manufacturers in that kind of highly dynamic environment the product development implies to react as soon as possible to customer requirements and at the same time optimise the capital investment.

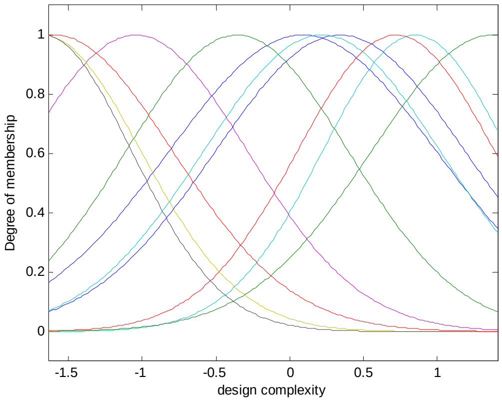

Fig 2 (a) automatically generated ANFIS model

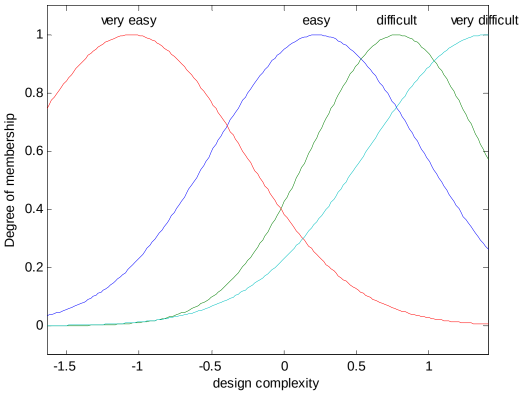

Fig 2 (b) simplified ANFIS cost model

Fig 2 Comparison of the membership functions for the input variable "number of colors".

The results show that the accuracy of the simplified model (SANFIS) remains acceptable compared whit the automatically generated ANFIS model. As an illustration, the figure 2 shows the impact of the first step in the simplification algorithm for the input variable “design number of colours”. Here the simplified membership functions are more easily interpretable as it allows assigning more readable linguistic markers ('easy', 'mean' and 'complex' sets instead of 11 fuzzy sets).

The table 1 shows the impact of the rule reduction step. This result shows that the simplified model has slightly less accurate results, but the developed simplification process allows keeping the significance level of the results and at the same time improves the rule base interpretation (7 instead of 11 inference rules). The reduced rule base makes possible to develop a methodology to build adaptable systems able to: predict the outcome of a decision-making process and provide an understandable explanation of a possible reasoning.

Table 1. Hybrid Neuro-Fuzzy Cost Estimation Model Simplification results

Cost Model	Inputs	MFs	Rules	Validation		Test	
				RMSE	NRE	RMSE	NRE
ANFIS	1 2 3 4	11 11 11 11	11	1.4932	5.1%	5.4464	20.5%
SANFIS	1 2 3 4	3 4 3 4	7	1.4918	6.2%	2.7877	12.4%

The final step consists in rule base simplification to obtain incomplete rules. Between global variable removal and selection done at rule level, from (Guillaume *et al.*, 2004) we introduce an intermediate selection level. It allows for evaluating the influence of a given variable within a context defined by the other inputs, and represented by a group of rules. The context implementation requires a rule distance function. The simplification stage tolerates some loss of accuracy while being guided by new indices complementary to the usual numerical performance index.

Table 2. Knowledge rule base

R	Number of pattern	Number of fabric colour	Number of pattern colour (complexity)	Lot Size	Cost
1	*very few*	*One*	*Easy*	*Very short*	f_1
2	*Few*	*Few*	*Easy*	*Short*	f_2
3	*Few*	*Average*	*Average*	*Very short*	f_3
4	*Average*	*Few*	*difficult*	*large*	f_5
5	*A lot*	*Average*	*difficult*	*Average*	f_6
6	*Average*	*One*	*difficult*	*Average*	f_7
7	*Average*	*A lot*	*difficult*	*Very short*	f_{10}

The SANFIS CERs are convenient when the system to model is highly variable, and we need to extract knowledge by using linguistic interpretation of the simplified rule set (Table 2). This fact is very important to enhance the use of cost as design variable in industrial activities when very often the cost drivers are aesthetical features with soft attributes (Leneau *et al*., 2003).

5. CONCLUSION AND PERSPECTIVES

The proposed model allows improving the product development process by taking advantage of the product and process information available in the design and process software tools. The most important fact for highly dynamic environments as textile industry is the availability of multi model tool which helps to reach a trade-off between accuracy, interpretability and time pressure in a highly dynamic business environment

More exactly, the methodology developed in this paper will improve the textile product development process by:

- A better comprehension of the system to be modeled by extracting knowledge to the Simplified hybrid neuro-fuzzy interpretation.
- The possibility of integration of aesthetical features as cost drivers that could act as a resource for designers.
- The improvement of the designer visibility, in order to have a better perception of the economical implication of his decisions taking into account the functional, aesthetical and structural parameters.
- A better communication quality between the designer (Stylist or Engineer) with the production process and the supply chain partners.
- Product development and validation time reduction in order to make better and faster customer response.

This kind of universal function approximation property give encouragement for finding increasingly better models but also recognizing that there was a limit depending on the structural elements used and their application field. As mentioned in (Leneau *et al*., 2003), the way as the interactions between soft and hard cost drivers of the product must be studied.

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