Algorithms and Decision Making Methods for Filter Design Tool Selection for a Given Specification in Online-CADCOM Platform

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Abstract. *This contribution presents the development of a multi-criteria decision model intended for decision support in selecting a filter design tool based on specific selection criteria. The multi-criteria decision model will serve as the basis for the development of an expert system to be implemented in code and integrated in the telecommunications engineering software solution Online-CADCOM. The multi-criteria decision model is implemented as a Decision Matrix and combines set theory based option filtering with the MAUT method for option ranking.*

Introduction

The Online-CADCOM system, described in [1], [2], [3], [4] is developed to integrate available online tools solving different computer-aided design tasks and combining tools for complex task solving. Tools are integrated in Online-CADCOM after verification, estimation, classification and characterization. The characterization passport is the unified description model introduced in Online-CADCOM and filled for each tool. The classification of the CAD tools in Online-CADCOM follows the structure of the Daniel Gajsky Y-model and consists in 2 panels with categories and subcategories in each of them, corresponding to different design levels and different circuits and system types. "Analog filters" is one of the subcategories in the category Analog circuits in Panel 1. Analogue filters design is fully automated and a set of free online tools are available, most of them proposed by IC and component providers. This creates a class of tools, which are either equivalent or have important application area coverage. This gives multiple opportunities to the designer to find solutions, but on the other side each tool has specific characteristics and application area limits which are visible from the passports. The motivation of the research described in this paper is to propose the algorithm for filter design tool selection, given a filter specification. When the number of tools with high degree of equivalence is as high as with analogue filter design, it makes sense to facilitate the selection with a suitable decision making algorithm. The paper describes the main characteristics of the filter specification to be used for tool selection based on tools passports and then proposes a decision-making algorithm for automatic filter design tool selection, thus enabling the development of a decision support system in Online-CADCOM.

2. Analog filter design tools and criteria for filter design tool selection in Online-CADCOM

The online analogue filter design tools characterized in Online-CADCOM are:

- AADE Filter Design tool (AADE) [5].
- LC filter design (LCFD) [6];
- FilterCAD 2.0., Linear Technology [7];
- Webench Filter Designer (WBFD), Texas Instruments [8];
- Analog Filter Wizard, (AFW) Analog Device [9];
- FilterLab (Microchip) [10];
- PAC Designer, (Lattice) [11].

The tools listed above propose filter design with different electronic elements – Passive LC filters, Crystal filters, Active filters with operational amplifiers, resistors and capacitors, Switched-capacitor filters, Programmable analogue circuits. This is strongly connected with the frequency range where this tool can be implemented. Usually the tools have limits for the applicable frequency range, for example the frequency limit in the FilterLab tool is 1 MHz. Thus the first criterion for selecting a filter design tool is the frequency range.

A survey of filter modelling tools was performed to gather the potential tool selection criteria. The relevant criteria were then selected by the engineering team and collected in a table containing the criteria types, their names, description, and possible values. Based on the analogue filter design methodology and the characterization passports of the tools enumerated above, we have defined a set of criteria for filter design tool selection:

- Frequency range;
- Type of filter: Lowpass, Highpass, Bandpass, Stopband, Allpass;
- Approximations: Butterworth, Bessel, Chebychev, Cauer (Elliptic);
- High roll-off slope in the Transition area – Cauer and Chebychev approximations;
- Flat gain in the passband: Butterworth, Bessel;
- No ripple in the stopband: Butterworth, Bessel, Chebychev;
- No ringing and overshoot in step response – Bessel approximation;

- Smooth roll-off in the passband (no ripple) and sharp roll-off slope in the transition area- Transitional filters;
- Minimal number of stages: Cauer;
- Linear phase;
- Phase compensation – correction of the nonlinearity of the phase – Allpass filters
- Small group delay – Gaussian filters, Bessel filters;
- Good shaping factor - Legendre filters;
- Antialiasing filters;
- Low power - Power estimation and power optimization;
- Low sensitivity – Tolerances and Monte Carlo or Worst case analysis;
- Low noise – Noise estimation and optimization;
- Low cost – Elements, PCBs and evaluation boards' prices available, bill of materials available;
- Circuit topologies – Multiple feedback, Sallen and Key, Biquadrate
- Small size – Size estimation.

By consulting with the engineering experts and researchers which have provided the list of available options and their characteristics and defined the filter modelling goals, we were able to reduce the list of approximately 60 filter modelling tools characteristics into a set of 18 selection criteria, grouped into criteria types. Using the defined set of criteria and the filter design tool data we have designed a table to be used for decision support, as described in chapter 4. We describe the relevant methodologies in the following chapter.

3. Methodology

The selection of an appropriate filter design tool requires the consideration of set of selection criteria. The awareness of the available tool options, the selection criteria and knowledge of engineering requirements requires considerable skills, which are typically obtained through laboratory exercises at faculty and engineering experience. In order to facilitate the learning process and the selection of the filter design tool for experienced and inexperienced users, we have decided to construct a decision support system that would incorporate the knowledge base of experienced telecommunications engineers and researchers and could be integrated in online learning tools used at the Faculty of Telecommunications, Technical University of Sofia.

3.1. Multi-criteria Decision Analysis (MCDA) methodology

As there are several criteria present in the filter design tool selection problem, we have examined several Multi-criteria Modelling Analysis (MCDA) methodologies in the development process. In this contribution, we present the original decision problem, the multi-criteria decision model development, and the decision modelling methodology used. Our development goal is a working, interactive online filter design tool selection decision support system.

A fundamental question in using a MCDA method to support a decision is "When does a multi-criteria decision problem requires the use of a structured approach and building of a computer-based decision model?" The general answer is that the MCDA approach is suitable when the decision-makers feel the decision is too large and complex to handle intuitively, or because it involves a number of conflicting objectives, or involves multiple stakeholders with diverse views or has to be performed repeatedly, with consistent results, or a formal, transparent and repeatable procedure is required for formal reasons, and therefore an undocumented, informal, intuitive approach would be insufficient.

A typical decision problem in the application of MCDA involves a static decision problem: a static set of decision goals and a static or variable set of options. In such a case, decision makers follow a set of goals, which are translated into a hierarchical structure of criteria x_i and their weights w_i, and then implemented as a utility function $F(O_k)$ which gives the utility of option O_k:

$$F(O_k) = F(w_1 x_{k1}, w_2 x_{k2}, w_3 x_{k3}, \cdots, w_n x_{kn}) \qquad (1)$$

,
with $w_n x_{kn}$ representing the utility function for a single criterion.

The resulting multicriteria model has a static structure, a static set of either quantitative or qualitative criteria, and static weights. The weights are constants representing the relative importance of individual criteria. In the application of such a model, each option is evaluated by entering the value of its individual criteria into the model, and a singular value representing the option utility is calculated. After analysis of results, the option with the highest utility value is then typically selected.

3.2. MCDA approach to the tool selection problem

The engineering tool selection problem importantly differs from the classic MDCA problem:

- the decision goals differ depending on the engineering problem that the tool is to be used on,
- due to variable goals, the criteria weights vary as well,
- some of the criteria can be exclusive due mandatory requirements for the engineering tool. These criteria have binary values (feature is present/not present),
- weights have a discrete set of values: mandatory, desired, and irrelevant.

In such a problem, the evaluation of the exclusive criteria produces a set of viable options, which have to be then ranked according to the utility function calculated from the non-exclusive criteria.

These specific qualities of the examined decision problem make the exclusive use of methods such as AHP, MAUT, or DEXi [12] impractical, as each use of the model requires changes to the multicriteria model as opposed to entering new options and their criteria values. Alternative methods, previously used in engineering, such as the Decision Matrix or Pugh method [13], [14] are better suited to this type of problem, and were used as a basis for the development of the solution, and combined with the MAUT [15] method to provide ranking of options.

Several decision modelling methods were examined in the development of the presented solution.

A good overview of MCDA methodologies and tools is presented in [16] and [17]. According to [18], successful selection of the most appropriate multi-criteria methodology should consider a range of different perspectives in order to comprehend all sides of the problem and, when necessary, consider inter-connections among the criteria. MCDM methods need to structure the decision procedure, to demonstrate the trade-off among the criteria, to assist decision-makers to reflect upon, articulate and apply worthy judgments related to satisfactory trade-offs, resulting in suggestions when considering alternatives, to estimate risk and uncertainty more consistently and reasonably, to simplify negotiation and to keep a record of how decisions are made.

Influence diagrams, are a useful tools for decision process modelling. According to [19], influence Diagrams can be viewed as informal precursors to belief networks (later called Bayesian networks [20]), which currently serve as the main computational tool for automated reasoning. According to [21], an influence diagram is a graphical representation of a decision situation. Methodologically is it a generalization of a Bayesian network, in which not only probabilistic inference problems but also decision making problems (following the maximum expected utility criterion) can be modelled and solved.

The decision-matrix method, also known as the Pugh method and Pugh Concept Selection, is a quantitative technique used to rank the multidimensional options of an option set, frequently used in engineering, and applicable to other multi-criteria ranking or selection decision. The decision matrix consists of a set of criteria, usually displayed in rows, and a set of options, usually displayed in columns. The relation between a criterion and an option is entered in the intersecting cells, and can represent the presence or absence of a quality described by the criterion, or a qualitative or quantitative value of the option for the criterion. In case of quantitative values, the decision matrix can be used as a quantitative MCDA model, however its structure imposes the limitation to a single level of criteria, i.e. hierarchical MCDA models cannot be formulated as a decision matrix.

The solution presented in this contribution is related to the system described by [22], as a prototype expert system that helps software project managers and software engineers in selecting the appropriate software development methodology, furthermore to the system described by [23] who present a rule based recommendation system that can be helpful to software developers in selecting the most appropriate SDLC model to be used for the development of a software product and to the solution presented by [24] whose paper presents an expert system based rapid prototyping (RP) system selection program incorporating the data on 39 commercially available RP systems, and finally to [25]), who describe a decision support system using qualitative and quantitative criteria in multicriteria decision tree for project planning support.

4. Results: Decision Matrix & MAUT model

Using the defined set of criteria from Chapter 2 and the filter design tool data from the characterization passport we have designed a table to be used as the Decision Matrix. Table 1 shows a fraction of the Decision Matrix, clearly displaying its structure and contained data. We chose not to include the whole table with 32 criteria due to space restriction. Rows are used to list the criteria types and individual criteria, while columns are used to indicate the presence or absence of filter design features per tool. Criteria value of »1« represents the presence of the feature described by the Evaluation Criteria while the value of »0« represents the absence of the feature. The Decision matrix in the presented form allows the algorithmic evaluation of individual options including the use of weights, given as »Criteria Priority«.

The weights (w_i) are not constants as mentioned in the previous chapter, but depend on user input, and can be therefore described as:

$$w_i = f(input) \tag{2}$$

User does not input weights directly, but chooses each criterion to be either:

- *mandatory*, or
- *desired*, with priority levels 1 (highest), 2 (medium), and 3 (lowest).

Priority levels are converted into weight values using this equation:

$$w_j = \begin{cases} \frac{3}{6}, if\ input(j) = 1 \\ \frac{2}{6}, if\ input(j) = 2 \\ \frac{1}{6}, if\ input(j) = 3 \end{cases} \tag{3}$$

,

thus ensuring the conformity with the MCDA convention [15] of

$$\textstyle\sum_{j=1}^{n} w_j = 1 \tag{4}$$

The decision matrix is implemented as table within a relational database, containing the data on options with each row/entry representing a single option, and columns/attributes containing the criteria values. The implementation of the decision matrix in a relational database simplifies decision model maintenance by avoiding code-level changes and accelerates system operation via implementation of a part of the option evaluation via database server-side execution in SQL code.

Table 1: Decision Matrix structure

Criteria Type	Criteria Priority	Evaluation Criteria	Options						
			AADE	LCFD	FilterCAD	FilterLab	WBFD	AFW	PAC-Designer
Frequency range/ Filter elements	*f(*input*)*	1Hz-12MHz (active filters)	0	0	0	0	1	1	0
	…	….	…	…	…	…	…	…	…

Option evaluation is conducted using set theory and relational algebra based instructions to execute a set of rules for filter design tool selection. User requirement entries/replies to questions are used to generate the sets of suitable options per criteria, and the SQL intersect operation is used to combine these sets and thus generate the composite set of suitable options.

In the foreseen use case, the user is presented with a sequence of questions aiming at filtering the set of viable filter design tools. Every question allows the user to define a feature (criteria) as either mandatory, desired, or irrelevant, and selecting the criteria priority, thus setting the criteria weight.

The criteria set as mandatory by the user are used to construct the set of viable options, i.e. tools that offer all mandatory features. To accelerate the filtering of viable options we have decided to move the filtering processing to the database side.

First the set of viable options VO is generated by producing an intersection of the sets of options O that satisfy individual mandatory criteria.

Written using relational algebra and set theory as:

$$VO = \bigcap_{i=1}^{n} \prod_{OptionId} \sigma_{X_i=True}(O) \quad (5)$$

,

with X_i with indexes $i = 1..n$ representing the mandatory criteria specified by the user, and $\sigma_{X_i=True}$representing the selection operation in relational algebra.

The options O_k in the viable set VO are then evaluated and ranked according to the desired criteria using MAUT [15] equation for the utility function $F(O_k)$:

$$F(O_k) = \sum_{j=1}^{n} w_j u_j(x_{kj}) \quad (6)$$

.

Consequently the viable options are to be displayed to the user in descending order according to their final score, i.e. utility, facilitating the selection of the Analog Filter design tool in Online CADCOM platform.

5 Conclusion

Based on the study performed in the paper a MCDA based decision support system is to be developed to support the Analog Filter design tool in Online-CADCOM platform. The approach will be extended to design in different categories of circuits and systems where a set of online CAD tools with high degree of equivalence is available. The boom of online tools led to development of portals or pools of online tools as for example Martindale's Center [26], but in those pools, tools are neither estimated nor characterized and there is not an interactive mode proposed for users. The novelty in the approach proposed in the paper is based on the estimates and characterization passports of online tools in the platform Online-CADCOM which are implemented further for automated support of designers in tool selection and development of interactive mode for users.

The following step is the development of a rule-based expert system to be integrated in the telecommunications engineering software solution Online-CADCOM, and used as a decision aid selecting the appropriate filter modelling tool. It is to be open-ended and able to incorporate additional filter modelling tools and decision criteria. The planned development will include design of the data model for the knowledge base, the design of user interface and coding of the user interface and inference engine using web technologies (PHP, JavaScript).

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