A FUZZY-BASED APPROACH TOWARDS CONCEPTUAL DESIGN IMPROVEMENTS FOR MECHATRONIC SYSTEMS

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ABSTRACT

In the presence of multiple interacting criteria, designing an integrated multidisciplinary product such as mechatronic systems, is not a trivial task and requires a systematic and concurrent methodology to achieve optimal design. Thus, there is an urgent need for a comprehensive tool to facilitate decision-making in the design process. During the conceptual design phase and after a careful assessment of design objectives for each alternative, a nonlinear fuzzy integral can be used for aggregation of different criteria and providing a global score reflecting the sense of design satisfaction. The goal of concept evaluation is to compare the generated alternatives against the design criteria and to select the best one for further developments into a product. In this paper, we introduce a fuzzy-based approach in accordance with the proposed multicriteria conceptual design to know on which criteria for a selected concept an improvement should be done in order to get the maximal possible overall score. As an application, the mechatronics design of a robotic visual servoing system is analyzed at the end.

Keywords: Mechatronics Design; Concept Evaluation; Fuzzy Aggregation.

UNE MÉTHODE FUZZY VERS DES AMÉLIORATIONS DE DESIGN CONCEPTUELLE POUR LES SYSTÈMES MÉCATRONIQUES

RÉSUMÉ

En présence de multiples critères qui interagissent, la conception d'un produit multidisciplinaire intégré tel que les systèmes mécatroniques n'est pas une tâche facile et nécessite une méthodologie systématique et concurrente pour obtenir une conception proche de l’optimal. Donc, il y a besoin de développer un outil pour faciliter la prise de décision dans le processus de conception. Au stade de la phase de design conceptuel, et après une évaluation des objectifs de conception pour chaque alternative de conception, une intégrale floue non linéaire peut être utilisée pour l'agrégation de différents critères et fournir un score global reflétant le la capacité du concept à satisfaire les critères de conception. L’objectif de l'évaluation conceptuelle est de comparer les alternatives de concepts générées contre les critères de conception et de choisir la meilleure pour le développement en produit final. Dans cet article, nous introduisons une approche basée sur la logique floue en lien avec la conception conceptuelle multicritère proposée pour savoir sur quels critères, pour un concept sélectionné, une amélioration devrait être effectuée afin d'obtenir le score global maximal. En tant qu'étude de cas, la conception mécatronique d'un système robotique avec control visuel est présentée.

Mots-clés : Conception mécatronique ; Évaluation conceptuelle ; Agrégation floue.

1 INTRODUCTION

A Mechatronic system is a synergic integration of cooperative mechanical, electronics, computer and information technology components, designed for improving control, automation, efficiency, and intelligence [1-3]. Designing mechatronic systems is often a highly complex task because of the high number of their components, their multi-physical nature and the couplings between the different engineering domains involved. To tackle this issue, a systematic and concurrent design approach is needed to replace the often used sequential design approach in which different engineering disciplines are dealt with separately [4]. Generally, the design process including of mechatronic systems, includes three major phases: “conceptual design”, “detailed design”, and “prototyping and improvements”. Conceptual design is an early stage of design in which concepts are selected and employed to solve a given design problems and then a decision is made on how to interconnect these concepts into an appropriate system architecture [5]. Moreover, at this stage, a complete and consistent listing of the requirements and behaviors is required as well as a thorough identification of critical parts of the solution that affects the overall performance. Rzevski [6] proposed a multi-agent based conceptual design of mechatronic systems. He claimed that the best design architecture would consist of a network of intelligent decision making units able to reach decisions through the process of negotiation. However, by analyzing their case study, one can notice an extensive use of sensory components and control agents as well as geometrical variables which all together increases the cost of development and decreases the system reliability. Coelingh et al. [7] proposed a formulation for conceptual design of a mechatronic system. They carried out a classification of standard transfer functions, plant models, and closed-loop systems and successfully applied this method to the design of a motion electromechanical system. Although their approach seemed to be limited to specific motion control systems rather than a general mechatronic design.

During the conceptual design stage, a number of problems and limitations are encountered when dealing with selection of components and choosing between alternatives for software and control strategies. This is due to the insufficient support of the multi-criteria nature of mechatronics systems design, which calls for decision making across various disciplines. In such cases, the designers usually choose the most available and feasible components to meet their requirements. Such decisions can often lead to a functional product, but rarely guarantee an optimal one. This outcome generally occurs due to the lack of a unified and comprehensive definition for performance criteria and also lack of knowledge about the co-influences and correlations between them. Moulianitis *et al.* [8] proposed a methodology for decision making in conceptual mechatronic design based upon an evaluation index including three criteria: intelligence, flexibility, and complexity. Weight factors were applied to highlight the importance of each criterion and the evaluation score has been formulated based on t-norm and averaging operators. However, this methodology investigates a limited, discrete search space and does not consider interactions between criteria. De Silva [9] proposed to associate performance indices to the mechatronic subsystems within an indicator, called “mechatronic design quotient (MDQ)” and maximizing this indicator after integrating all the subsystems. Based on this work, Behbahani [10] introduced and systematic framework for design of a mechatronic system by using the concepts of mechatronic design quotient (MDQ) in a concurrent design approach, where fuzzy logic has been used to define the correlation factors. The methodology of MDQ was implemented in pilot projects [11], and has proved to be efficient; however measurement and determination of criteria for design are more qualitative and no systematic assessment approach was presented. Mohebbi *et al*. [12] introduced a new multi-criteria profile (MMP) for concept evaluation in design of mechatronic systems consisting of five main elements: intelligence, reliability, complexity, flexibility and cost.

Based on the assessed MMP for each concept and using various aggregation techniques, a global concept score (GCS) was calculated to ease the procedure of concept evaluation, selection and modification. For the aggregation of criteria, three operators were formulated based on Choquet integral, Sugeno integral and a fuzzy-based neural network [13, 14]. They successfully applied their method to various case studies of robotic systems and mechatronic quadrotor drones. They also suggested that a web-based software implementation would considerably add to the reliability of fuzzy measures required in the design aggregation process by incorporating a wider and more correlated range of designers and industrial specialists. In this paper and in accordance with the proposed multicriteria conceptual design based on MMP and Choquet integrals, we propose a fuzzy-based approach to identify the criterion or criteria and corresponding subsystems needing the most improvements in order to get the maximal possible overall score. The rest of the paper is organized as follows. The next section gives a brief overview on the conceptual design of mechatronic systems while Section 3 describes the previously developed methodology based on Mechatronic Multicriteria Profile (MMP) as a design evaluation index. The fuzzy-based decision support and criteria aggregation are described in Section 4 alongside the necessary definitions on fuzzy measures and integrals and their properties. In Section 5, we propose a design improvement method by introducing a new fuzzy-based index quantifying the worth of a criterion to be improved in a selected design concept. Section 6 describes a case study to show the use of the proposed method in a conceptual design activity for a robotic visual servoing system and finally, Section 7 discusses the concluding remarks of the presented research.

2 CONCEPTUAL DESIGN OF MECHATRONIC SYSTEMS

Conceptual design is an early stage of design in which the designers choose amongst the concepts that fulfill the requirements defined by a design problem and then decide how to incorporate these concepts into a proper system architecture. Usually, a large number of candidate concepts exist for a given design problem and a considerable amount of uncertainty arises about which of these solutions will be best fitted to the given criteria and objectives. This is more evident when the designer has to meet highly dynamic and interconnected design requirements specifically for a multi-disciplinary system such as mechatronic products where mechanical, control, electronic and software components interact and a high-quality design cannot be achieved without simultaneously considering all subsystems.

Optimal mechatronics design requires a systematic evaluation approach to choose amongst the design solutions. This evaluation includes both comparison and decision making [15]. It is crucial to take into account both correlation between system requirements and also interactions between all subsystems. Based on sets of design specifications, candidate solutions are generated in a conceptual design stage. The goal of concept evaluation is to compare the generated concepts against the requirements and to select the best one to push to the detailed design and prototyping stages. This process is illustrated in Figure 1.

3 MECHATRONIC MULTICRITERIA PROFILE (MMP)

Providing a comprehensive set of criteria to concurrently evaluate and synthesize the designs is one the important challenges during the conceptual design phase. Generally, making design decisions with multiple criteria is often performed using a Pareto approach. Without the identification of the system performance parameters and understanding of their co-influences, achieving optimal solutions is far from reach. In order to form an integrated and systematic evaluation approach, the most important criteria and their related sub-criteria have been quantified by our work in [12] to form an index vector of five normalized elements called Mechatronic Multicriteria Profile (MMP) as follows:

$$MMP = [MIQ, RS, CX, FX, CT]^T \tag{1}$$

where MIQ is the machine intelligence quotient, RS is the reliability score, CX is the design complexity, FX is the flexibility and CT is cost of manufacture and production. Figure 2 describes the MMP with all corresponding sub-criteria. We also define m_i as the values for the members of MMP sorted in ascending order such that $m_1 \leq m_2 \leq \cdots \leq m_n$ and $0 \leq m_i \leq 1$.

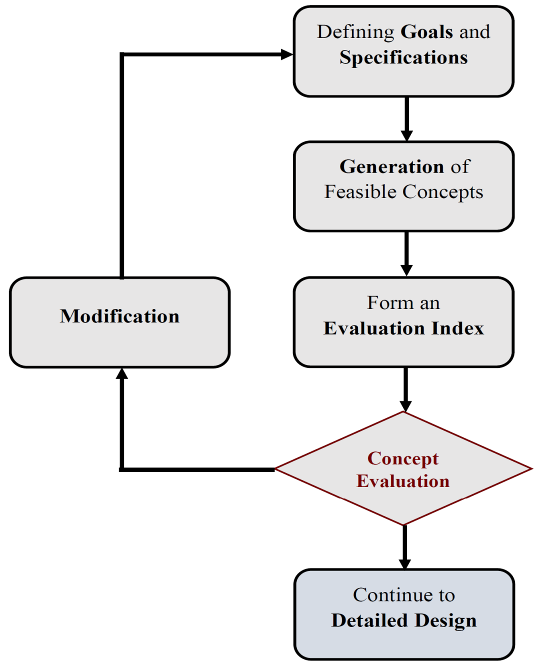


Fig. 1. Concept evaluation in design

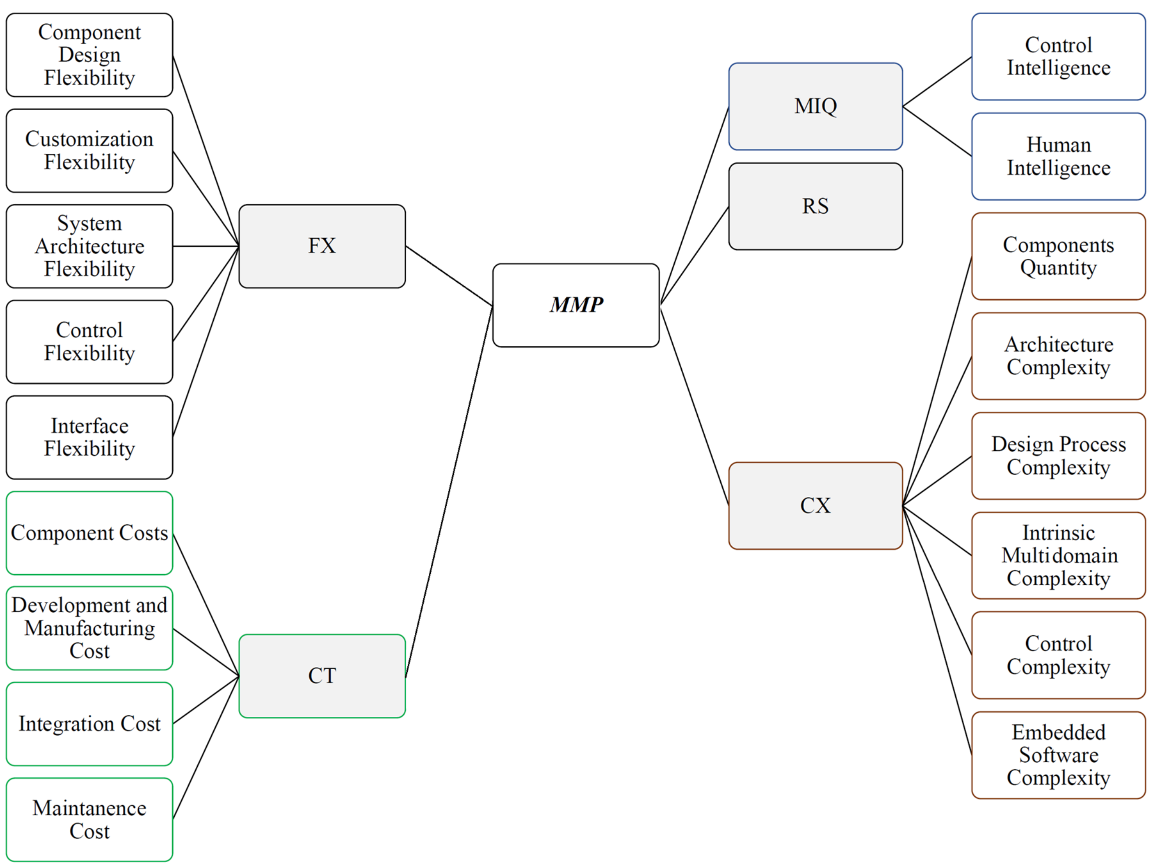


Fig. 2. Mechatronic Multicriteria Profile (MMP) and all of its sub-criteria

After determination and normalization of each sub-criterion, and by using a linear combination of weighted factors, the value of each main criterion will be assessed as follows:

$$m_i = \sum_{j=1}^{n} w_j \bar{\phi}_j \tag{2}$$

where $\bar{\phi}_j$ is the assessed value for each criterion, n is the total number of sub-criteria, and w_j are the weights associated to each sub-criterion assigned based on the designer's intuition.

4 FUZZY MEASURES AND CHOQUET INTEGRALS

Aggregation of multiple criteria to form an overall performance index is an important problem in many disciplines. The main factor in the determination of the structure of such aggregation operators is the relationship between the criteria involved. Choquet integral is a nonlinear fuzzy integral that has been successfully used for the aggregation of criteria in the presence of interactions. After Assessing all MMP criteria and their corresponding subsets, an effective comparison algorithm is needed to be incorporated in mechatronic conceptual design. A global concept score (GCS) as a multi-criteria evaluation index can be defined as follows in order to enable the designers to compare between the feasible generated design concepts.

$$GCS = S(\overline{f_1}, \overline{f_2}, \dots, \overline{f_n}) . \prod_{i=1}^{m} g(f_i), \tag{3}$$

where $\bar{f_i}$ are the normalized criteria values, $S(.)$ represents an aggregation function which is the well-known Choquet integral here, and $g(f_i)$ indicates whether a design constraint has been met (binary value).

Choquet integral provides a weighting factor for each criterion, and also for each subset of criteria. Using Choquet integrals is a very effective way to measure an expected utility when dealing with uncertainty, which is the case in design in general and mechatronics design in particular. Using this technique and by defining a weighting factor for each subset of criteria, the interactions between multiple objectives and criteria can be easily taken into account. The weighting factor of a subset of criteria is represented by a fuzzy measure on the universe N satisfying the following fuzzy measure (μ) equations:

$$\mu(\phi) = 0, \qquad \mu(N) = 1. \tag{4}$$

$$\emptyset \subseteq A \subseteq B \subseteq N \ \rightarrow 0 \leq \mu(A) \leq \mu(B) \leq 1 \tag{5}$$

where A and B represent the fuzzy sets [16]. Let μ be a fuzzy measure on X, whose elements are denoted by $x_1, x_2, \dots, x_n$ here. The discrete Choquet integral of a function $f: X \rightarrow \mathbb{R}^+$ with respect to μ is defined by:

$$C_\mu(f) = \sum_{i=1}^{n} \big(f(x_i) - f(x_{i-1})\big)\mu(A_{(i)}), \tag{6}$$

where indices have been permuted so that $0 \leq f(x_1) \leq f(x_2) \leq \dots \leq f(x_n)$. Moreover, $A_{(i)} = \{(i), \dots (n)\}$, and $A_{(n+1)} = \emptyset$ while $f(x_0) = 0$. It is worth mentioning that in our design case $f(x_i)$ are the quantified criteria values. Table 1 shows the most common semantic interactions among criteria pairs and the corresponding fuzzy measures.

Table 1. Fuzzy Interactions and Measurements

#	Description of Interaction	Fuzzy Measurement
I	Negative Correlation	$\mu(i,j) > \mu(i) + \mu(j)$
II	Positive Correlation	$\mu(i,j) < \mu(i) + \mu(j)$
III	Substitution	$\underset{T \subseteq Y \setminus i,j}{\mu(T)} < \begin{Bmatrix} \mu(\mathrm{T} \cup i) \\ \mu(\mathrm{T} \cup j) \end{Bmatrix} \simeq \mu(\mathrm{T} \cup i \cup j)$
IV	Veto Effect	$\mu(T) \approx 0 \text{ if } T \subset Y, \mathrm{i} \notin \mathrm{T}$
V	Pass Effect	$\mu(T) \approx 1 \text{ if } T \subset Y, \mathrm{i} \in \mathrm{T}$
VI	Complementarity	$\underset{T \subseteq Y \setminus i,j}{\mu(T)} \simeq \begin{Bmatrix} \mu(\mathrm{T} \cup i) \\ \mu(\mathrm{T} \cup j) \end{Bmatrix} < \mu(\mathrm{T} \cup i \cup j)$

A lattice representation can be used for describing fuzzy measures in the case of a finite number of criteria. For simplicity we use μ_{ij} instead of $\mu(\{i,j\})$. Using a 2-additive model the Choquet integral can be re-formulated to incorporate importance and interaction indices as follows:

$$C_\mu(f) = \sum_{i=1}^{n} \phi(\mu, i) f(x_i) - \frac{1}{2} \sum_{\{i,j\} \subseteq N} I(\mu, ij) \left| f(x_i) - f(x_j) \right| \tag{7}$$

where $\phi(\mu, i)$ is the importance index for a criterion i and can computed by the Shapley value [17] as:

$$\phi(\mu, i) = \sum_{T \subseteq N \setminus i} \frac{(n-t-1)!\, t!}{n!} [\mu(T \cup i) - \mu(T)]. \tag{8}$$

The Shapley value ranges between 0 and 1, and represents a true sharing of the total amount $\mu(N)$, since:

$$\sum_{i=1}^{n} \phi(\mu, i) = \mu(N) = 1. \tag{9}$$

It is convenient to scale these values by a factor n , so that an importance index greater than 1 indicates an attribute more important than the average. The interaction index $I(\mu, ij)$ for any pair of criteria *i* and *j* is defined as follows [17]:

$$I(\mu, ij) = \sum_{T \subseteq N \setminus i,j} \frac{(n-t-2)!\, t!}{(n-1)!} [\mu(T \cup ij) - \mu(T \cup i) - \mu(T \cup j) + \mu(T)]. \tag{10}$$

where T is a subset of criteria. The interaction index ranges in [-1, 1]. For $I(\mu, ij) = 0$ criteria i and j are independent while $I(\mu, ij) > 0$ means there is a complementary among *i* and *j* and that for the decision making, both criteria have to be satisfactory in order to get a satisfactory alternative. If $I(\mu, ij) < 0$ then there is a substitutability or redundancy among criteria *i* and *j*. This means that the satisfaction of one of the two criteria is sufficient to have a satisfactory alternative. It is worth to note that a positive correlation leads to a negative interaction index, and vice versa. The fuzzy measures should be specified in such a way that the desired overall importance and the interaction indices are satisfied.

There exist a variety of methods for identifying $(2^n - 2)$ fuzzy measures which later on will be used in a Choquet integral for aggregating interactive criteria [18, 19]. The designer can intuitively choose the fuzzy measures or use a systematic approach to calculate them.

5 CONCEPT IMPROVEMENT METHODOLOGY

It is quite usual in a conceptual design process that the design alternatives which are evaluated are not fixed and the designer wishes to obtain recommendations on how to improve a concept. More precisely, the designer is eager to know on which criterion or criteria an improvement should be done in order to get the maximal possible improvement of the overall global score. The concept is selected based on the process explained in Section 4 and can be described by a profile $F = MMP\ (f) = [f_1, f_2, \dots, f_n] \in \mathbb{R}^n$ which based on the MMP, here $n = 5$. Most of the time the designer wants to know how to improve a profile F into a new profile $\acute{F}$ such that the overall evaluation $S(f_1, \dots, f_n)$ reaches a given expectation level. This can be mathematically formulated as an optimization problem as follows;

$$\min\ c(F, F') \\ \begin{cases} F' \in \mathbb{R}^n \\ \forall i \in N, F' \geq F \\ C_\mu(F') = \eta \end{cases} \tag{11}$$

where $C_\mu(.)$ is the Choquet aggregation function, η is the expectation level, and $c(F, \acute{F})$ quantifies the cost to improve option F into a new profile $\acute{F}$. The above optimization problem provides the new profile $\acute{F}$ that should be reached. The main drawback of this approach is that the designer is not always able to easily construct a new option corresponding to the profile $\acute{F}$. She/he will thus proceed iteratively by transforming F into a better profile F_1, then F_1 into F_2, and so on, until the expectation level η is reached. The recommendation the designer is willing to have is a priority indication of a criterion in F that should be improved. Thus, there will not be a semantic about the intensity of the improvement that the overall score will gain. To tackle this problem, we can use a worth index proposed by Labreuche [20] and denoted by $w_A^\psi(F)$ which quantifies the improvement worth of a set of criteria $A \subseteq N$ from the profile F, subject to the evaluation function $\psi(.)$. This index can be calculated as follows:

$$w_A^\psi(F) = \int_0^1 \left[\psi\left((1-\tau)F_A + \tau 1_A, F_{N\setminus A}\right) - \psi(F)\right] d\tau. \tag{12}$$

Above equation gives the mean impact of uniformly improving all of criteria in subset A at the same time, where one assumes that all possible levels of improvement (from sticking to F_A up to reaching the ideal profile 1_A) have the same probability to occur. It is important to note that the subset A should not be restricted in singletons $\{1\}, \{2\}, \dots, \{n\}$ and any coalition of criteria $\{i, j, k, \dots\}$ should be considered in the process. Moreover, if the evaluation function $\psi(.)$ is constant over criteria set A, then $w_A^\psi(F) = 0$. As an example, let's say we would like to calculate the worth index for a coalition $A = \{1, 3\}$ among criteria where $n = 5$. Then we get $F_A = [f_1, f_3]$ and $F_{N/A} = [f_2, f_4, f_5]$. Consequently, we can rewrite Equation (12) for the coalition $A = \{1, 3\}$ as follows:

$$w_{\{1,3\}}^\psi(F) = \int_0^1 [\psi([(1-\tau)f_1 + \tau], f_2, [(1-\tau)f_3 + \tau], f_4, f_5) - \psi(F)] d\tau. \tag{13}$$

We continue calculating the worth index for all the coalitions- from singletons to the largest coalition, and choose the largest value as an index of the worth for improving the criteria subset which is most beneficial towards the global score. For a profile consisting of n criteria we would get $(2^n - 2)$ subsets which will not include the null set $\emptyset$ and N . Thus, for $n = 5$, we need to calculate $(2^5 - 2) = 30$ indices. The general proposed process of concept improvement is depicted in Figure 4.

Equation (12) can be extended as follows, so as to take into account the improvement cost c from Equation (11) which can be arbitrarily defined by the designer;

$$\hat{w}_A^{\psi}(F) = \int_0^1 \frac{\left[\psi\left((1-\tau)F_A + \tau 1_A, F_{N\setminus A}\right) - \psi(F)\right]}{c\left(F, \left((1-\tau)F_A + \tau, F_{N\setminus A}\right)\right)} d\tau. \tag{14}$$

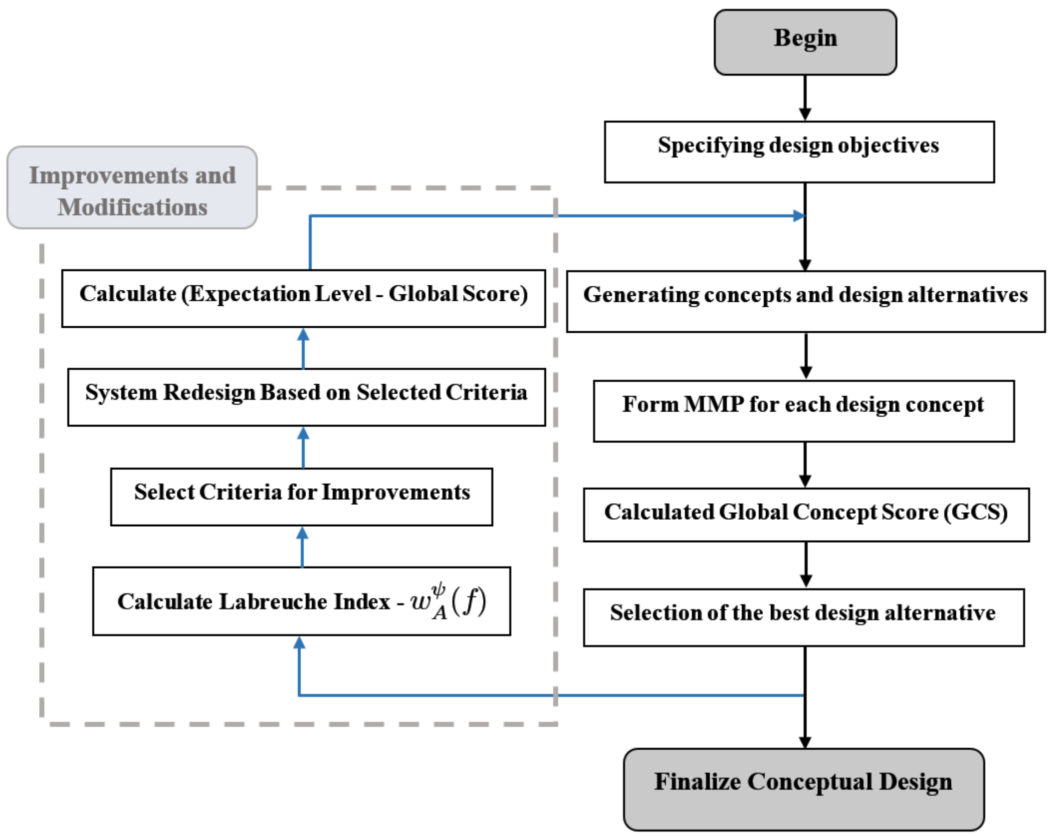
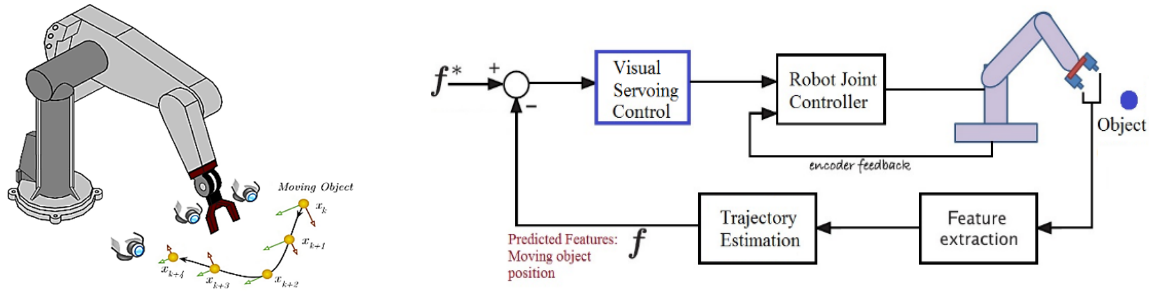


Fig. 3. The process of concept improvement using fuzzy integrals and worth index

6 CASE STUDY: DESIGN OF A ROBOTIC VISUAL SERVOING SYSTEM

During last decades, using robotic systems and automation machineries is considerably increased in various industrial, urban and exploratory applications. However, robotic systems are generally limited to operate in highly structured environments. Thus, integration of vision sensors and generally "visual servoing" control systems helped solve this problem by digitally reconstructing the environment and producing non-contact measurements of the working area for the machine [21]. In this section, a case study of concept improvement for a 6 DOF manipulator equipped with robotic visual servoing system is presented. Figure 5 shows a schematic of the proposed robotic visual servoing system and its components.



(a) (b)

Fig. 4. A robotic visual servoing system and its components, (a) 6-DOF robot manipulator and the moving object, (b) Visual servoing control system

The conceptual design of the above system has been previously carried out and described in [12]. The objective was to design a robotic visual servoing system capable of tracking and catching a moving object with the maximum mass of 1 kg and maximum velocity of 1 m/s within 3 seconds after the object enters the vision system's field of view, and also within the area of motion with dimensions of 500mm×500mm×500mm. For the selected design alternative, we have the following assessments for the elements of MMP sorting in ascending order:

$$F = [0.8, 0.905, 0.964, 1, 1]^T = [CT, CX, FX, RS, MIQ]^T, \quad (15)$$

For which the resulting global score using Choquet integral is $C_\mu(F) = 0.9462$. Table 2 shows the identified fuzzy measures used in the proposed multicriteria conceptual design process.

Table 2. Fuzzy measures used for the conceptual design process using MMP methodology

$\mu_1 = 0.3105$	$\mu_{12} = 0.4537$	$\mu_{13} = 0.5989$	$\mu_{14} = 0.2892$	$\mu_{15} = 0.6244$
$\mu_{123} = 0.7893$	$\mu_2 = 0.2450$	$\mu_{23} = 0.4724$	$\mu_{24} = 0.5381$	$\mu_{25} = 0.4863$
$\mu_{124} = 0.4537$	$\mu_{135} = 0.7105$	$\mu_3 = 0.1802$	$\mu_{34} = 0.4708$	$\mu_{35} = 0.1797$
$\mu_{125} = 0.8070$	$\mu_{145} = 0.6507$	$\mu_{245} = 0.8269$	$\mu_4 = 0.2717$	$\mu_{45} = 0.5212$
$\mu_{134} = 0.5965$	$\mu_{234} = 0.7844$	$\mu_{345} = 0.5180$	$\mu_{235} = 0.5113$	$\mu_5 = 0.2018$
$\mu_{1234} = 0.8082$	$\mu_{1235} = 0.9403$	$\mu_{1345} = 0.8082$	$\mu_{2345} = 0.8082$	$\mu_{1245} = 0.8546$

Moreover, using the values from Table 2, the importance and interaction indices can be also calculated which result in the following values.

$$I = [I(i,j)] = \begin{bmatrix} 0.2232 & -0.1018 & 0.1082 & -0.2931 & 0.1121 \\ -0.1018 & 0.2481 & 0.0472 & 0.0213 & 0.0394 \\ 0.1082 & 0.0472 & 0.1662 & 0.0189 & -0.2023 \\ -0.2931 & 0.0213 & 0.0189 & 0.1691 & 0.0476 \\ 0.1121 & 0.0394 & -0.2023 & 0.0476 & 0.2002 \end{bmatrix} \quad (16)$$

$$\Phi = [\phi_1, \phi_2, \phi_3, \phi_4, \phi_5]^T = [0.2232, 0.2481, 0.1662, 0.1691, 0.2002]^T. \quad (17)$$

Now by using an algorithm incorporating the discrete form of the Equation (12) with an interval number of $m = 20$, we can calculate the worth index for all the criteria coalitions in F. The coalition on which the worth index is the largest is $\{CT, CX\}$ for which $w^{\psi}_{\{1,2\}}(F) = 3.481\text{E}-4$. This result is completely natural as these two criteria have the worst evaluation scores $[0.8, 0.905]$, and also the greatest importance indices $[\phi_1, \phi_2] = [0.2232, 0.2481]$. Moreover, there is a strong correlation (negative interaction index) among them. Hence, it is more rewarding to improve both cost (CT) and complexity (CX) rather than any of them individually as $w^{\psi}_{\{1\}}(F) = 0.539\text{E}-4$, and $w^{\psi}_{\{2\}}(F) = 0.785\text{E}-4$. Table 3 shows the calculated worth index for some coalitions in *F*.

Table 3. Worth index $w^{\psi}_{A}(F)$ for several coalitions in MMP

A	$w^{\psi}_{A}(F)$
$\{CT, CX\}$	$3.481\text{E}-4$
$\{FX, RS\}$	$1.181\text{E}-4$
$\{CT, MIQ\}$	$1.994\text{E}-4$
$\{CT, CX, MIQ\}$	$3.091\text{E}-4$
$\{CT\}$	$0.539\text{E}-4$
$\{CX\}$	$0.785\text{E}-4$

After finding the intended criteria coalition, we can proceed with the case specific design improvements and try to redo the process in an iterative manner as described in Figure 3 until we reach a desirable global score threshold.

7 CONCLUSIONS

In this paper, and in accordance with a previously proposed multicriteria conceptual design methodology, we have proposed an approach based on a nonlinear fuzzy integral to identify a set of criteria within a design concept, for which an improvement should be done in order to get the maximal possible overall score. In the beginning, we gave a brief introduction on the conceptual design of mechatronic systems and the Mechatronic Multicriteria Profile (MMP) as an index for design evaluation. Then, the fuzzy-based decision support and criteria aggregation have been described. Moreover, we proposed a design improvement method by introducing a new fuzzy-based index quantifying the worth of a criterion to be improved in a selected design concept and at the end, the mechatronics design of a robotic visual servoing system has been analyzed as an application of the proposed approach. Finally, the overall design improvement approach has been formulized in a process to facilitate its integration into real-world applications.

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