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A fuzzy integral fusion approach in analyzing competitiveness patterns from WCY2010

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ABSTRACT

Information fusion is a known technique in enlightening features, patterns, and multiple criteria decision making. However, the decomposed information of the fusion has always been unknown, making its applications limited. This research proposes a fuzzy integral combined with a fitness fusion (named as the fuzzy integral fusion, FIF) to induce features and consequently reveal the decomposed information empirically illustrating the dominance benchmark and the fusion effect for approximations. For illustration, the proposed fuzzy integral fusion is applied on World Competitiveness Yearbook 2010 to analyze the European crisis nations (Greece, Italy, Portugal, Spain) and the European welfare nations (Denmark, Finland, Norway, Sweden). The results showed that the European crisis nations should improve their institution framework to effectively raise their business finance efficiency.

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1. Introduction

National competitiveness represents a fusion power for a nation to enhance its people's lives and cope with worldwide challenges [1–3]. The fusion techniques can provide an aggregated information to expound features [4,5], pattern [6,7], and multiple criteria decision making [8–11]. However, the fusion techniques still have difficulty in analyzing the diverse competitiveness. There are two potential problems in this issue. First, the fused competitiveness cannot be decomposed to provide thorough information, making the implications short of sufficient information. Second, fusion uncertainty always brings complexity [7,12], which can be observed especially on the three types of fusion results: positive, negative, and independent, resulting to mixed combinations [4,5]. A fusion result is positive when the fused result is more than the sum of the individuals. In contrast, a negative result means that the fused result is less than the sum of the individuals. An independent result stays in the middle of both, which causes more uncertainty in the combinations and makes the fusion techniques limited on their applications.

With the aforementioned problems, the key challenges for analyzing competitiveness are summarized as the following:

- Short of fusion information. Fusion information is becoming more and more important for the nations to survive the diverse competition in this e-era of globalization. *World Competitiveness Yearbook* (WCY) is the most well-known annual report of national competitiveness [2]. It linearly aggregates diverse competitiveness. However, neither fused nor decomposed information is provided.
- Challenges of inconsistency. Currently, the most popular fusion technique for utilities is by integrating the fuzzy measure and the fuzzy integral. However, it faces inconsistency challenges. For instance, applying the fuzzy integral and the fuzzy measure on two criteria and two utilities might encounter 'Why is u_2 involved in the interaction effects while u_1 is not?', which is formulated with gray color in Eq. (1) and illustrated in Fig. 1.

$$\begin{aligned} u_k(Q) &= \int u \bullet d(q) = u_2\, g(\{q_1, q_2\}) + (u_1 - u_2)\, g(\{q_1\}) \\ &= u_2(g_1 + g_2 + \lambda g_1 g_2) + (u_1 - u_2) g_1 \\ &= u_1 g_1 + u_2 g_2 + \lambda u_2 g_1 g_2 \end{aligned} \tag{1}$$

In Eq. (1), k represents an object, $Q = \{q_1, q_2\}$ is a criteria set, u represents a utility function, g represents a fuzzy measure function, u_1 and u_2 are utility values of criteria q_1 and q_2 with respect to k, g_1 and g_2 are fuzzy densities of criteria q_1 and q_2, and λ is an interaction degree.

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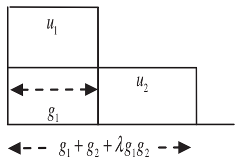

Fig. 1. An inconsistency challenge of integrating the fuzzy measure and the fuzzy integral.

- Challenges of uncertainty reduction. The fusion uncertainty from both the fuzzy measure and the fuzzy integral makes their integration a more serious uncertainty. So far, there has been no any proposed decomposing technique for information fusion, thus making the uncertainty reduction still short of a penetrating function.

To overcome the above challenges, the fuzzy integral, the fuzzy measure, and a fitness fusion are integrated, termed as the fuzzy integral fusion (FIF), to generate fusion features, provide both fused and decomposed information, and feedback selected criteria for further fusion, as shown in Fig. 2 with three stages. In Stage I, DRSA and the fuzzy measure identification are integrated into a generalized fuzzy integral, presented in Proposition 3 of Section 3 [13–17]. In Stage II, Applying the generalized fuzzy integral generates the fusion features. Stage III, a fitness fusion is designed to select a candidate criterion for the next round or terminates the fusion. Furthermore, decomposed information of the features such as the benchmarking, fused effect, and qualities are collected at the right bottom corner.

This paper has two main parts. The first part discusses the design and implementation of FIF. The second applies FIF to analyze the European crisis nations (Greece, Italy, Portugal, and Spain) and the European welfare nations (Denmark, Finland, Norway, and Sweden) based on WCY 2010. The remainder of this paper is organized as follows: Section 2 reviews the information fusion, Section 3 presents the fuzzy integral fusion, Section 4 addresses application results of FIF, and Section 5 presents discussions and implications for the European crisis nations. Finally, concluding remarks are stated to close the paper.

2. Literature review

The International Institute for Management Development (IMD) annually publishes *World Competitiveness Yearbook* (WCY), a well-known report which ranks and analyzes how a nation's environment can create and develop sustainable enterprises. Information from this report is used as the competitiveness dataset in this research [2]. Discussions related to the competitiveness fusion are presented in the following.

2.1. Information fusion

The information fusion is a technique proposed by Keller in 1990 [14] which aims to search the maximal agreement between the objective evidences and the subjective expectation on various sources [18,19]. The fuzzy integral defined with respect to a fuzzy measure becomes the major tool. Four years after, the information fusion was applied for classification [20], multiple criteria decision making [4], and feature fusion [5]. Technically, the fuzzy integral was developed in formulae as:

$$F_{\text{integral}}(f_1, f_2, \ldots, f_m) \cong \vee_{j=1}^{m}(f_j \wedge g(A_j))$$

where $(Q, F_{\text{integral}}, g)$ is a measure space, $\cong$ means aggregation values based on power set of $\{f_1, f_2, \ldots, f_m\}$, $\vee$ is an integral operator, f_j is a preference function $f{:}Q \to [0,1]$, and $f_1 \leqslant f_2 \leqslant \ldots \leqslant f_m$ is a permuted sequence by index j, $A_j = \{A_1, A_2, \ldots, A_j\}$ is an aggregation set, and $g(A_j)$ is the fuzzy measure for A_j. The information fusion with the fuzzy integral and the fuzzy measure together has three types of interaction results, namely:

1. Negative synergy (or redundancy) – is when the importance of combining two different features is less than the sum of two individuals.
2. Positive synergy (complement) – is when the importance of combining two different features is more than the sum of two individuals.
3. Independency – is when each fusing resource independently brings its contribution into the recognition.

In recent years, the information fusion has been popularly applied in many fields. To name a few, a generalized Choquet fuzzy integral was proposed to assign confidence for a land mine detection [21], a fusion model was applied in biometrics for decision analysis [22], an application of combining fuzzy measure and nonlinear integral based on multi-regressions was developed for data mining [23], and an application for evaluation was proposed to help in distance learning [10].

Currently, the fuzzy measure is being extended to perform as a multiplicative utility function which makes information fusion as simple as a function [17].

2.2. Extended Fuzzy Measure (EFM)

EFM multiplies implication probabilities and preferences into utilities and then extends the fuzzy measurement to accumulate utilities for competitiveness. The following properties are their

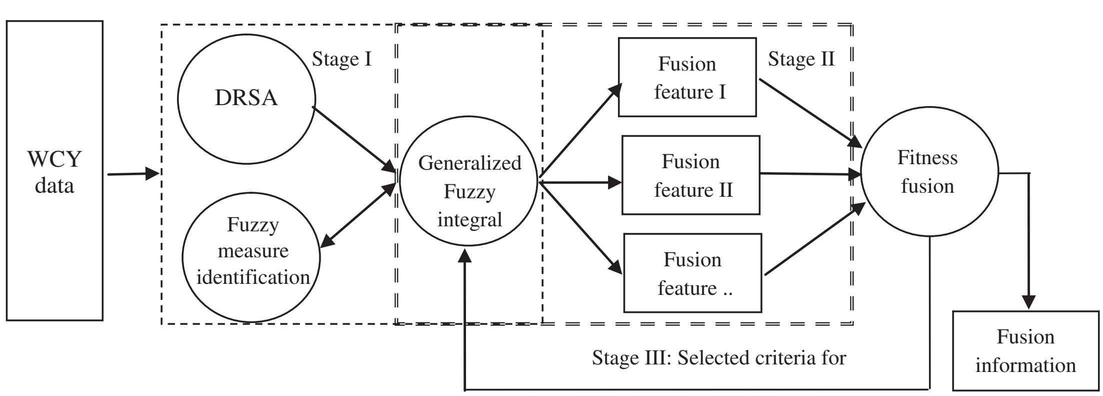

Fig. 2. The methodology of the fuzzy integral fusion.

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