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Sequential three-way decision and granulation for cost-sensitive face recognition

Huaxiong Li[a,*], Libo Zhang[a], Bing Huang[b], Xianzhong Zhou[a]

[a] Department of Control and Systems Engineering, School of Management and Engineering, Nanjing University, Nanjing 210093, China
[b] School of Technology, Nanjing Audit University, Nanjing, Jiangsu 211815, China

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ABSTRACT

Many previous studies on face recognition attempted to seek a precise classifier to achieve a low misclassification error, which is based on an assumption that all misclassification costs are the same. In many real-world scenarios, however, this assumption is not reasonable due to the imbalanced misclassification cost and insufficient high-quality facial image information. To address this issue, we propose a sequential three-way decision method for cost-sensitive face recognition. The proposed method is based on a formal description of granular computing. It develops a sequential strategy in a decision process. In each decision step, it seeks a decision which minimizes the misclassification cost rather than misclassification error, and it incorporates the boundary decision into the decision set such that a delayed decision can be made if available high-quality facial image information is insufficient for a precise decision. To describe the granular information of the facial image in three-way decision steps, we develop a series of image granulation methods based on two-dimensional subspace projection methods including 2DPCA, 2DLDA and 2DLPP. The sequential three-way decisions and granulation methods present an applicable simulation on human decisions in face recognition, which simulate a sequential decision strategy from rough granule to precise granule. The experiments were conducted on two popular facial image database, which validated the effectiveness of the proposed methods.

1. Introduction

Computer-aided face recognition systems have received much attention over the past few decades. Numerous face recognition techniques were developed [1–7]. Such techniques are capable of cooperating with human users in many applications, e.g., entrance-guard system, citizenship identification system, computer access control, and electronic surveillance [8]. Most previous studies on face recognition attempted to achieve a low misclassification error, i.e., the higher the recognition accuracy, the better the method [8]. In many real-world scenarios, however, this evaluation is not reasonable. The reasons lie in two aspects. First, in real world face recognition, different kinds of misclassifications will lead to different costs. For example, consider an entrance guard system via face recognition techniques, the cost of misrecognizing an impostor as an office member would be much larger than that of misrecognizing an office member as an impostor, since the former may cause much worse consequence than the latter [9]. The examples indicate that the misclassification costs are usually quite different in reality, and simply minimizing the misclassification error rate may not be a good objective for face recognition systems. It is necessary to develop face recognition techniques that can deal with cost-sensitive classification problem [10]. Second, a high-quality image data set is necessary for high-precise recognition. However, in many real-world applications, it is difficult to obtain high-quality images, or it may associate with extra costs to get these high-quality images. In the case that we only have some low-quality images, a delayed decision may be a better choice than an immediate decision, since the cost of making a delayed decision is lower than that of making a certain decision. However, with the increasing of available high-quality images, the cost of deciding a delayed decision may be higher than that of deciding positive or negative decision, thus many delayed decision will be definitely decided to positive or negative region. These decisions lead to a three-way decision strategy [11–15].

The methodology of three-way decisions are commonly used in human daily decision making [14] and widely applied in many theoretic fields, such as management sciences [16], social judgement theory [17], and hypothesis testing in statistics [18]. More practical applications of three-way decisions were reported in numerous

* Corresponding author.
E-mail addresses: huaxiongli@nju.edu.cn (H. Li), mg1315013@smail.nju.edu.cn (L. Zhang), hbhuangbing@126.com (B. Huang), zhouxz@nju.edu.cn (X. Zhou).

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fields, including, medical decision making [19–22], peering review process [23], government and investment decision [24,25], Email spam filtering [26,27], text classification [28], clustering analysis [29–31], semi-supervised learning [32], knowledge granulation [33], and multi-agent decision [34]. Although the essential ideas of three-way decisions are frequently used in both theoretic and practical research fields, there are few literatures concerning a unified formal description on three-way decisions [14]. To address this issue, Yao presented a general overview on existing three-way decisions researches, and extended the rough sets-based three-way decisions to a much wider frontier, which outlines a unified theory of three-way decisions [14]. It is emphasized that the evaluation of acceptance and rejection is a primitive notion for characterizing the satisfiability of objects, which can be regarded as a key concept of three-way decisions.

Yao [14] and Hu [35] presented a comprehensive survey on three-way decisions. According to the methods used for evaluating acceptance and rejection, they classified the three-way decisions into three categories: three-way decisions with a pair of poset-based evaluations, three-way decisions with one poset-based evaluation, and three-way decisions with one poset-based evaluation [14,35]. From a theoretical point of view, such evaluations can be determined by a set of criteria, such as costs, benefits, and degrees of desirability [14]. Further studies on the criteria of evaluation may be a meaningful research direction in three-way decision field. Given a certain criteria of evaluation, the objective of three-way decisions can be formulated as an optimization problem to minimize or maximizing the evaluation values. Therefore, different kinds criteria lead to different three-way decision models. For example, if one considers the cost or risk as a criterion of evaluation, and discuses the uncertainty of decision from a rough set point of view, then the purpose of three-way decisions is to minimize the overall costs among three decision regions, which leads to a rough set-based three-way decisions [12,15,36–38]. Decision-theoretic rough sets model is a typical rough set-based three-way decisions model, in which a quantitative inclusion of an equivalence class is used for evaluating acceptance and rejection [36]. It can be regarded as a generalized rough set-based three-way decisions model [12]. If one considers a qualitative inclusion of an equivalence class for evaluating acceptance and rejection, then a Pawlak rough set-based three-way decisions model is derived, which can be viewed as an extreme case of decision-theoretic rough set-based three-way decision model [14]. Moreover, if one considers methods to evaluate the acceptance and rejection, or uses further approaches to represent the uncertain and insufficient information of a concept, then some new models of three-way decisions can be derived, such as interval set-based models [14,39,40], fuzzy set-based models [41], and shadowed sets-based models [42,43]. In this paper, we focus on the rough sets based three-way decisions models, especially on the decision-theoretic rough sets-based models, since it takes the cost as an evaluation for acceptance and rejection, which is suitable for the cost-sensitive classification and decision problems.

Recently, rough sets based three-way decisions models received much attention in decision-making and artificial intelligence research fields [13,44,45,24,27,29,46]. It presents a well semantics explanation on how to classify an instance into positive, negative or boundary regions based on cost-sensitive classification strategy. A core content of rough sets based three-way decisions is to introduce boundary decision to traditional two-way decisions (positive and negative decisions) [13], and seek an optimal decision from the three regions by minimizing the decision cost. It is evident that, in some cases, the boundary decision may achieve a lower cost than positive and negative decisions do if available information for immediate decision is insufficient, which is consistent with human decision process [47]. For example in criminal investigation, it is difficult for a police officer to immediately identify a criminal from her/his first impression on facial features, although in memory she/he has recognized the person as a criminal. In this case, neither positive (criminal) nor negative (innocent) decision is immediately decided. The officer will delay the decision and collect more information for further decision, since this boundary decision will cause the lowest mistake cost. This decision method takes a typical three-way decision strategy.

If one considers the applications of rough set-based three-way decision in cost-sensitive face recognition, there are still two important problems need to be further studied. First, the boundary decision presents a delayed solution when available information is insufficient. However, if available information increases, the previous boundary decisions may be converted to positive or negative decisions. How to describe such dynamic sequential decision process is meaningful for applications. Second, how to evaluate the available information or granular feature of a facial image should be considered. Human vision can easily deal with face recognition from rough granule to precise granule. While for computer vision, it is difficult to describe the granular structure of an image and evaluate the available granular information for decision. To address these two issues, we propose a dynamic sequential three-way decision method for cost-sensitive face recognition. A series two-dimension subspace feature extraction methods including 2DPCA [4,48], 2DLDA [49] and 2DLPP [50,6] are introduced to describe the available information in facial image. The principal components induced from the subspace projections are adopted as the representations of the image granular structures. The proposed sequential three-way decision takes a dynamic strategy for face recognition. In the case that available information is insufficient, i.e., rough granule case, some images are wrong recognized or decided as boundary decisions, neither positive nor negative decision, thus the decision costs stay in a high level. With the increasing of available information, the decision costs decrease since the decisions are more precise and some boundary images are converted to certain positive or negative region. Such sequential three-way decision presents a simulation on human dynamic decision process in cost-sensitive face recognition.

This paper is an extended version of the paper [45]. The remainder of this paper is organized as follows. In Section 2, we briefly introduce some related work on three-way decision. In Section 3, we formulate the cost-sensitive face recognition problems. In Section 4, we propose a dynamic cost-sensitive sequential decision method. Section 5 presents two-dimensional subspace methods for facial image granulation, which are used to extract granular features from the images, such that cost-sensitive sequential decision can be conducted on the granular features. Section 6 reports the experimental results and analysis. Finally, in Section 7, we conclude the paper.

2. Related work

The theories and methods on three-way decisions have been developed for a long history, which can be traced back to some early studies on the social judgement theory [14,17]. Many recent works further developed the theories and applications of three-way decisions [27,29,35,46,51,52]. Hu presented a comprehensive survey on three-way decisions in [35]. In general, there are two main aspects in the three-way decisions researches. The first aspect is the researches on the background of three-way decisions [27,29,35,46,51,52], and the second aspect is the theoretical framework researches on three-way decisions [14,35].

The first aspect mainly focuses on the extension researches of rough sets, including two categories works: the extensions of Pawlak rough sets to new rough set models, and the extensions