Fuzzy Logic and Multi-biometric Fusion
An Overview

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Keywords: Multi-Biometric Fusion, Fuzzy Logic, Fuzzy Fusion.

Abstract: Fuzzy logic has been proposed to improve various aspects of multi-biometric applications including enhancements to the decision making of the application and the robustness to noisy data. This paper discusses recent work that utilized fuzzy logic techniques within the multi-biometric fusion problem. This discussion is presented under two categories, the type of authentication scenario and the nature of the fused data. The paper also presents an introduction to fuzzy logic and multi-biometric fusion. Based on the discussed works, this paper aims to establish current trends and research possibilities in this field.

1 INTRODUCTION

In order to improve biometric recognition, different types of multi-biometrics haven been studied. The multi-biometrics can be categorized into following types: multi-algorithm, multi-instance, multi-modal, multi-sample and multi-sensor biometrics. The category most relevant for this paper is multi-modal biometrics. In multi-modal biometrics, two or more biometric characteristics are used. E.g. the work of Lau et al. (Lau et al., 2004) and Hui et al. (Hui et al., 2007) made use of three characteristics: face, fingerprint and speech. The process of combining the results of multi-biometrics is called fusion. Ross et al. (Ross et al., 2008) name advantages of multi-biometrics in the areas of: universality, indexing, robustness, resistance to noisy data, continuity and fault tolerance. Based on these advantages other research has shown that multi-biometrics can improve performance of biometric recognition (Chang et al., 2003) (Hong et al., 1999).

Fuzzy logic is a way of reasoning by approximation that deals with vague or uncertain data by assigning them truth values between 0 and 1 (Zadeh, 1965). This allows the modelling of vague data, where for example a temperature could be 0.3 warm and 0.7 cold corresponding to the vague expression of "fairly cold". This is done in three steps. First each input is assigned to a linguistic variable. This step is called fuzzification. Then for each variable membership functions with different degrees of membership are obtained. Next, fuzzy rules can be utilized where logic can be applied to these membership functions. E.g. in the form of "**If** condition-1 **and** condition-2 **then** decision a". This decision often is used as the output for the fuzzy system. The process of converting this fuzzy output to a continuous value is called defuzzification.

Fuzzy logic can be used in biometrics to deal with the quality of the samples of characteristics, which can be affected by lighting, noise and user-device interactions. It can also be used to perform the fusion and therefore enhance the decision making of a multi-biometric application. Another idea is to use this principle for continuous authentication. Continuous authentication aims to have the individual authenticated using an ongoing identification or verification process. E.g. while the subject is using a PC or while it is inside a specific area of a building.

In the next two sections further details along with the advantages of fuzzy logic and multi-modal fusion will be presented. The section after will present the research done in order to combine these two disciplines. Finally, a conclusion will be given where trends and research opportunities will be discussed.

2 FUZZY LOGIC

An application using fuzzy logic has the advantage of being able to deal with both numerical as well as linguistic data. This can be of advantage when dealing with vague or incomplete data. Being able to deal with data referring to concepts such as "high confi-

Maul F. and Damer N..
Fuzzy Logic and Multi-biometric Fusion - An Overview.
DOI: 10.5220/0005193302180222
In *Proceedings of the International Conference on Pattern Recognition Applications and Methods* (ICPRAM-2015), pages 218-222
ISBN: 978-989-758-076-5

dence", "low confidence" or "quality" offers possibilities in both decision making as well as coping with external factors of an application.

Mendel describes a fuzzy logic system (FLS), see Figure 1, as follows (Mendel, 1995): An FLS can be viewed as a mapping from inputs to outputs. Rules may be provided by experts or can be extracted from numerical data. In either case, these rules are expressed as a collection of "If Then" statements, e.g. "IF u_1 is very warm and u_2 quite low, THEN turn v somewhat to the right." The fuzzifier maps the crisp input to fuzzy sets. This is needed to work with the aforementioned rules. The inference engine of the FLS maps fuzzy sets to fuzzy sets. It handles the way in which rules are combined, which helps in making decisions. Finally, the defuzzifier maps the output sets into crisp numbers.

George et al. state that fuzzy logic is used in the areas of civil engineering, mechanical engineering, industrial engineering, computer engineering, robotics and in reliability theory (George J and Bo, 2008). Examples for such an approach can be found in a review by Chen et al., where different ways of using fuzzy logic to improve the ability of dealing with vague or unclear data on the semantic web are shown (Chen et al., 2012). Furthermore Mendel names a list of real world applications, that make use of fuzzy logic (Mendel, 1995). These applications are used for control (e.g. space shuttle docking (NASA)), scheduling and optimization (e.g. stock market analysis (Yamaichi Securities)) and signal analysis for tuning and interpretation (e.g. TV picture adjustment (Sony)).

3 MULTI-MODAL FUSION

A multi-modal biometric system is a multi-biometric system where more than one biometric characteristic is used to recognize a subject. In order to make a final decision regarding this recognition, the different information need to be combined or merged (fusion). There are different ways to implement such a fusion process. Ross et al. name the following (Ross et al., 2008):

Decision-level Fusion. In decision-level fusion the decisions of the uni-biometric systems are used to compute the final decision. E.g. using a "AND" and "OR" rule-set.

Rank-level Fusion. If the biometric system is used for identification, the output can be viewed as a ranking of the enrolled identities. The goal of rank-level fusion is to consolidate this output by the individual biometric subsystems in order to derive a consensus rank for each identity. Which then can be used to build the final decision.

Score-level Fusion. In score-level fusion the comparison scores output of the different biometric comparators are combined to generate a new match score that can be subsequently used by the verification or identification modules for rendering the final decision.

Feature-level Fusion. Using this fusion method, the feature sets originating from multiple different biometric algorithms are consolidated into a single feature set. This is achieved by the application of appropriate feature normalization, transformation and reduction schemes.

Sensor-level Fusion. This fusion method refers to the consolidation of either raw data obtained using multiple sensors, or multiple snapshots of a biometric characteristic using a single sensor.

Approaches using fuzzy logic to improve multimodal fusion focused mainly on decision-level fusion and score-level fusion.

4 LITERATURE SURVEY

4.1 Classification Criteria

In this section, previous research work using fuzzy logic to improve multi-biometric fusion are presented under two discussion categories. The first category differentiates the proposed systems based on the authentication scenario intended, weather it is a conventional (static) or continuous authentication scenario. The second part will present the previous work depending on the kind of information that was fused and used fuzzy logic techniques to achieve their goals.

4.2 Type of Authentication

4.2.1 Static Authentication

Conventional or static authentication is the identification or verification scenario common for biometric systems where the recognition decision is built only once and subsequent actions are performed based on that decision.

In the approach proposed by Park et al. (Park et al., 2006), fuzzy logic is utilized in the decision making level of the system in order to improve the verification rate and to lower the FAR and FRR. The proposed system fused information gathered from a face comparator and a speaker comparator. Unsupervised principal component analysis (PCA) was used for face

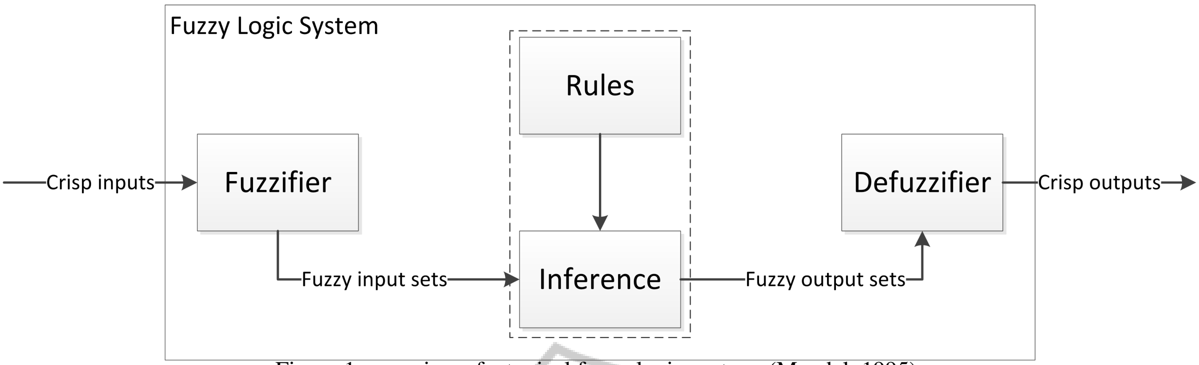

Figure 1: overview of a typical fuzzy logic system (Mendel, 1995).

Table 1: Table of work that was used for static authentication. Ordered by mention in this paper.

Multi-modal human verification using face and speech	(Park et al., 2006)
Fuzzy logic decision fusion in a multimodal biometric system	(Lau et al., 2004)
Adaptive weight estimation in multi-biometric verification using fuzzy logic decision fusion	(Hui et al., 2007)
Quality based Speaker Verification Systems using Fuzzy Inference Fusion Scheme	(Hamid and Ramli, 2014)
An efficient multi-modal biometric person authentication system using Fuzzy Logic	(Vasuhi et al., 2010)
Multimodal biometric system fusion using fingerprint and iris with fuzzy logic	(Abdolahi et al., 2013)

recognition (Rowley et al., 1998). For speaker verification Hidden Markov Models (HMM) (Samaria and Young, 1994) were used by the authors. The experiments carried out by the authors achieved a verification rate of 99.99% at an FAR of 0.001%, which is an improvement over the individual modalities' performance of 98.5% and 97.37% verification rate for face and speaker comparators respectively, both at an FAR of 0.01%.

Lau et al. also proposed a system where fuzzy logic is used to improve a verification system (Lau et al., 2004). The authors combined fingerprint, face and speaker verification into a system using fuzzy logic to dynamically alter the weights of the different characteristics. External factors, e.g. lighting, are measured and then used by the fuzzy logic system to determine the weights for the final decision calculation. Only the weights for face and fingerprint recognition were calculated using the fuzzy logic based approach. In different experiments the proposed approach achieved EER values in the range of 0.31% to 0.81% compared to the base line fusion by weighted avarage scores with EER values in the range of 0.50% and 0.84%.

Hui et al. presented an improvement over the system proposed by Lau et. al. by adding a method to compute a measurement of noise in the speaker recognition (Hui et al., 2007). This signal-to-noise ratio is then used by the fuzzy logic system to calculate the optimized weight for the speaker comparison. In experiments utilizing paired test sets the proposed solution was able to show an overall improvement of the EER by 42.1% compared to a solution based on weighted average fusion.

A similar system, where fuzzy logic is used to compute weights for the different biometric scores, was proposed by Hamid et al. (Hamid and Ramli, 2014). The authors performed experiments using both the Sugeno-type and Mamdani-type fuzzy models. The paper did not present a comparison to base line fusion solutions, however, it clearly showed the performance gained by the fuzzy fusion approach compared to single modalities.

Vasuhi et al. proposed a system where the final decision is made by fusing the comparison scores produced by speaker and fingerprint matchers with fuzzy logic rules (Vasuhi et al., 2010). For voice recognition, the authors used a text dependent speaker verification using HMM. For the feature extraction and classification Mel-frequency Cepstral Coefficients (MFFCC) were used (Hasan et al., 2004) (Biswas et al., 2007). The authors proposed and used the Cross Correlation of Field Orientation (CCFP) as bases for their fingerprint comparator. The work did not present any statistically significant results, however it claims to present an efficient solution that overcomes the drawbacks of individual sensors.

Abdolahi et al. follow a similar approach, where

Table 2: Table of work that was used for continuous authentication. Ordered by mention in this paper.

Ensuring the identity of a user in time: a multi-modal fuzzy approach	(Azzini et al., 2007)
A fuzzy approach to multimodal biometric continuous authentication	(Azzini et al., 2008)
Continuous authentication using mouse dynamics	(Mondal and Bours, 2013)

the scores of fingerprint and iris matchers are used as inputs for the fuzzy logic system, which calculates the final decision (Abdolahi et al., 2013). Discussed results only show advantages with respect to uni-modal base comparators.

4.2.2 Continuous Authentication

In highly sensitive environments, it might be necessary to confirm the identity of subjects at random intervals to prevent identity substitution after the initial authentication. For these cases, systems using continuous authentication were proposed.

Two papers by Azzini et al. focus on the integration of fuzzy logic into a solution for continuous authentication (Azzini et al., 2007) (Azzini et al., 2008). In both systems, fuzzy logic was used to calculate the decisions using the scores scored by different biometric sources as its input. The authors conclude their work with a positive view on the achieved performance with emphasis on the capabilities of the solution when the context variables in the acquisition are not optimal.

In theory, fuzzy logic techniques can be used to build a more robust trust model for continuous authentication. Recent advances regarding continuous authentication and trust models can be seen in the work of Mondal et al. (Mondal and Bours, 2013).

4.3 Type of Data Fused

4.3.1 Fuzzy Logic Decision

Here, the input for the fuzzy logic system is the biometric scores from different sources. The fuzzy logic solution tries to optimally fuse those scores into a final unified biometric decision. Much previous work followed this approach to improve the performance of biometric systems. The papers by Abdolahi et al., Azzini et al., Park et al. and Vasuhi et al. (Abdolahi et al., 2013) (Azzini et al., 2007) (Azzini et al., 2008) (Park et al., 2006) (Vasuhi et al., 2010) were based on this technique. More details about those works and the achieved performances are discussed in Section 4.2.

4.3.2 Fuzzy Adaptive Weight Score-level Fusion

For this approach, fuzzy logic is used to calculate optimal weights for the scores of different biometric sources using external factors such as capture quality measures (e.g. illumination). The fusion itself is a weighted score-level fusion. This methodology was used by Hamid et al., Hui et al. and Lau et al. (Hamid and Ramli, 2014) (Hui et al., 2007) (Lau et al., 2004).

4.3.3 Fusion Using Non-biometric Data

Azzani et al. included a strictly non-biometric input into the fuzzy logic fusion (Azzini et al., 2007) (Azzini et al., 2008). A password entered by the subject is fused along with the biometric information to produce a final authentication decision. While the score of the password is simply represented by a 1 if it was correct, and a 0, if it was not correct, this inclusion was noteworthy and can be extended to different non-biometric information.

5 CONCLUSIONS

This paper presented a literature survey of the utilization of fuzzy logic within multi-biometric systems. It discusses the previously presented work based on two criteria. First is the authentication scenario, whether it is a conventional (static) or a continuous authentication. The second criterion is based on the type of fused information as well as the nature of the fuzzy logic application. All reviewed papers show that the use of fuzzy logic can improve multi-biometric systems in certain scenarios. The presented works, especially the ones conducted in (Azzini et al., 2008), show that selecting appropriate fuzzy membership functions and defining the most beneficial set of fuzzy rules is not a trivial task and might require time and effort. These parameters also depend strongly on the application in question. Unfortunately none of the experiments in the previous work were conducted using a large and publicly available database. Future work should, therefore, be more comparable to existing solutions and include the investigation of the appropriate scenarios for the utilization of fuzzy logic. It should as well discuss methods that should be followed to optimize the parameters of the fuzzy logic solution. Another task for future work would be the verification of these approaches by using large and open accessibly database. Reproducibility and verification of the results these proposals have produced might support a trend of continuing and expanding research in combining fuzzy logic with biometric recognition.

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