Template security analysis of multimodal biometric frameworks based on fingerprint and hand geometry

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Summary
Biometric systems are automatic tools used to provide authentication during various applications of modern computing. In this work, three different design frameworks for multimodal biometric systems based on fingerprint and hand geometry modalities are proposed. An analysis is also presented to diagnose various types of template security issues in the proposed system. Fuzzy analytic hierarchy process (FAHP) is applied with five decision parameters on all the designs and framework 1 is found to be better in terms of template data security, templates fusion and computational efficiency. It is noticed that template data security before storage in database is a challenging task. An important observation is that a template may be secured at feature fusion level and an indexing technique may be used to improve the size of secured templates.

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Introduction

The branch of science, which deals with human recognition based upon biological, chemical or behavioural aspects is termed as biometrics. A system which is used for automatic human recognition used biometry is called as biometric system (Jain et al., 2008a). Biometrics has been used over ancient times for various applications of human identification. The traditional techniques of human recognition suffers from many limitations like ID cards may be lost...
or stolen and passwords may be hacked. Modern approach is based upon “what you are” and authenticates users using their biological traits (Jain et al., 2008a, 2004). Typically a biometric system consists of four important modules namely; Sensor, Feature extractor, Matcher and Template database. A module which is used to capture biometric trait from human body is called as sensor. Quality of the captured image is then assessed and feature extraction is performed to extract important feature points. The result of this process is a numerical set of values called as feature vector, which is then stored in system database. Multibiometric systems were introduced to overcome few of the limitations of unibiometric systems (Ross et al., 2006; Jain and Ross, 2004). Multibiometric system works by using multiple sensors or multiple algorithms/multiple modalities and a mix of all. A multibiometric system where multiple modalities of the same users are used for identification is called as Multimodal biometric system (Ross et al., 2006). The results of different modalities are then combined using a technique known as fusion. Different types of fusion techniques have been discovered for multibiometric systems which work at different levels (Ross et al., 2006; Jain and Ross, 2004). Typical examples of multimodal biometric include (Face, Fingerprint) (Christina et al., 2015), (Face, Fingerprint, Iris) [ADHHAR UID, India], (Fingerprint, Palm print) (Brindha and Natarajan, 2012) and (Iris, Face). Christina et al. (2015) discuss various types of security issues and challenges in multimodal biometric systems. Various template security schemes have been discovered for protection of biometric data (Jain and Ross, 2004).

Proposed multimodal biometric frameworks

The proposed multimodal system frameworks are based upon fingerprint and hand geometry biometric modalities. A multimodal framework 1 as shown in Fig. 1 is based on two modalities; namely fingerprint and hand geometry. In this case two different feature extractors are used for feature template generation. The templates are then fused together using a proper fusion technique. Then, fused template is finally stored in the database. In this framework templates may be protected during feature fusion process or after fusion takes place. A different framework 2 is little costly in terms of storage but better in fusion overhead. In this case two different feature templates are being generated but stored in separate database.

Third type of proposed multimodal biometric framework 3 is based upon having multiple feature extractors for both the biometric modalities and combining the templates. Multi algorithm multimodal type of system is used to improve the identification accuracy with added overhead of time complexities of algorithms.

In this system four different feature templates are generated and then finally the result is combined using ranking of results accuracy. In this design, rank level fusion is applied to arrive at final decision of recognition process.

Result analysis

Template security of a multi modal biometric framework may be analysed by using different performance parameters (Jain et al., 2008b; Christina et al., 2015). For an optimal design framework few of these parameters are need to be maximised while others has to be minimised. A process for choosing the better design where uncertainty lies in the performance parameters is based on fuzzy theory. The analytic hierarchy process (AHP) was proposed by T.L. Satty in 1980. Fuzzy analytic hierarchy process (FAHP) is a popular technique used to compare various systems with a number of decision parameters proposed in Csutora and Buckley (2001). A FAHP technique has been used in different applications for optimal decision problems (Lee et al., 2008; Chiu and Kaushal, 2015). Our work identifies five parameters affecting the design of multimodal biometric frameworks. Template generation involves the effort or complexity of feature extraction technique required to generate a feature template data in the multimodal biometric. Once feature template is generated, its security is most important parameter. Fusion overhead is the inherent effort and cost put in combining various results during multimodal biometric systems. Template size overhead is effective size of the template once it is generated or actual size before storage in the template database. Storage complexity is the actual number of bits required by a feature template on the disk for storage. FAHP is a six steps process, where firstly a ranked structure of all the parameters is constructed by making a pair wise comparison matrix. In next step consistency in the matrix is detected. Suppose that matrix is $A[n \times n]$ and elements are denoted as $a_{ij}$ then it will be consistent if satisfy the criteria as shown below

$$a_{ij} = 0.5. \quad a_{ij} + a_{ji} = 1,$$

$$\frac{1}{a_{ij}} - 1 = \left( \frac{1}{a_{ik}} - 1 \right) \times \left( \frac{1}{a_{kj}} - 1 \right) \quad (1)$$

Now next step is to calculate the positive fuzzy matrix for converting the scores of pair wise comparison in to fuzzy variables with their values lying between 0 and 1. Then fuzzy weights of the all decision parameters is computed using the

![Figure 1 Multimodal biometric framework 1.](image-url)
Table 1  Fuzzy pair wise comparison matrix with different decision parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Template generation</th>
<th>Template security</th>
<th>Fusion overhead</th>
<th>Template size overhead</th>
<th>Storage complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Template generation</td>
<td>0.5</td>
<td>0.1</td>
<td>0.5</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Template security</td>
<td>0.9</td>
<td>0.5</td>
<td>0.7</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>Fusion overhead</td>
<td>0.5</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Template size overhead</td>
<td>0.7</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Storage complexity</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 2  Fuzzy hierarchy based comparative analysis of multimodal frameworks.

<table>
<thead>
<tr>
<th>Proposed multimodal biometric framework</th>
<th>Template generation</th>
<th>Template security</th>
<th>Fusion overhead</th>
<th>Template size overhead</th>
<th>Storage complexity</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framework 1</td>
<td>H</td>
<td>H</td>
<td>VH</td>
<td>H</td>
<td>H</td>
<td>x</td>
</tr>
<tr>
<td>Framework 2</td>
<td>H</td>
<td>VL</td>
<td>L</td>
<td>H</td>
<td>VH</td>
<td>x</td>
</tr>
<tr>
<td>Framework 3</td>
<td>VH</td>
<td>L</td>
<td>VL</td>
<td>VH</td>
<td>VH</td>
<td>x</td>
</tr>
<tr>
<td>Framework 1</td>
<td>0.7</td>
<td>0.7</td>
<td>0.9</td>
<td>0.7</td>
<td>0.7</td>
<td>x</td>
</tr>
<tr>
<td>Framework 2</td>
<td>0.7</td>
<td>0.1</td>
<td>0.3</td>
<td>0.7</td>
<td>0.9</td>
<td>x</td>
</tr>
<tr>
<td>Framework 3</td>
<td>0.9</td>
<td>0.3</td>
<td>0.1</td>
<td>0.9</td>
<td>0.9</td>
<td>x</td>
</tr>
<tr>
<td>Weight</td>
<td>0.0642</td>
<td>0.3940</td>
<td>0.1440</td>
<td>0.342</td>
<td>0.0546</td>
<td>x</td>
</tr>
<tr>
<td>Framework 1</td>
<td>0.04494</td>
<td>0.2758</td>
<td>0.1296</td>
<td>0.2394</td>
<td>0.03822</td>
<td>0.72796</td>
</tr>
<tr>
<td>Framework 2</td>
<td>0.04494</td>
<td>0.0394</td>
<td>0.0432</td>
<td>0.2394</td>
<td>0.04914</td>
<td>0.41608</td>
</tr>
<tr>
<td>Framework 3</td>
<td>0.05778</td>
<td>0.1182</td>
<td>0.0144</td>
<td>0.3078</td>
<td>0.04914</td>
<td>0.54732</td>
</tr>
</tbody>
</table>

The formula (2), where $p$ is number of parameters

$$FW = (f_{w1}, f_{w2}, \ldots, f_{wp}) \text{, } f_{w1} = \frac{x_i}{\sum_{i=1}^{p} x_i},$$

where

$$x_i = \frac{1}{\left[ \sum_{j=1}^{p} \frac{1}{a_{ij}} \right] - p}.$$  \hspace{1cm} (2)

Step next to be followed is combining outcome of intuitive decisions by taking the geometric means. Finally the ranking is computed using the consistency ranking index by using formula

$$CRI = \frac{\sum_{i=1}^{p} a_{Fw_i}}{p - 1},$$

Consistency Ratio may be computed $CR = \frac{CRI}{RCI}$ \hspace{1cm} (3)

where RCI is random consistency index with different values.

Satty’s scale and fuzzy comparative scale may be classified in six categories namely; (I) lowest significant (1, 0.5), (II) moderate significant (3, 0.55), (III) strong significant (5, 0.65), (IV) strongly significant (7, 0.75), (V) strongly significant (9, 0.85), (VI) extremely strongly significant (9, 0.95).

For template security analysis of frameworks, suppose the ranks are given along with fuzzy membership function values as very high (0.9), high (0.7), medium (0.5), low (0.3) and very low (0.1). Using Eq. (2) the fuzzy weight matrix of five decision parameters is $FW = (0.0642, 0.3940, 0.1440, 0.342, 0.0546)$. From fuzzy weight matrix it is clear that template security is most important design parameter with weight of 0.3940 and followed by template size overhead. As shown in Table 1, the fuzzy comparison matrix is of the size of $5 \times 5$ and therefore the value of RCI is 1.12. The matrix is said to be consistent if consistency ratio CR < 0.1. Comparative template security analysis of proposed frameworks is shown in Table 2 by using weights of various parameters as computed earlier. CRI = 0.1 which is consistent.

Results clearly shows framework 1 is optimal design among all the proposed systems with top result of 0.72796 followed by framework 3.

Conclusion

In this work, three design frameworks using fingerprint and hand geometry were presented with their pros and cons. Five decision parameters were identified and used to analyse template security of the proposed multimodal frameworks. FAHP technique was used to select the optimal design with inherent uncertainty lying in various parameters. Among all, framework 1 with a value of 0.72796 found to be most suitable multimodal framework as far a template security is concerned. In framework 1, feature templates from two different modalities are combined at feature fusion level, where feature templates may be simultaneously secured as well. It is also found that template security and template size overhead are top two design parameters for multimodal frameworks.

References


