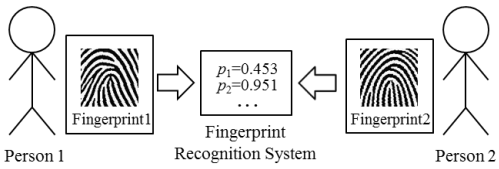

Figure 5. Basic idea of the fingerprint recognition system using proposed templates in the case that fingerprint recognition system has only one set of the transforms' orders. Therefore, each person does not need to have an IC card where a set of the transforms' orders is recorded

5. EER of proposed fingerprint templates

In this section, first, the behavior of the EERs of the fingerprint templates is investigated in case of Fig.4, that is, different sets of the transforms' orders for different fingers. The EERs are obtained based on the PV of the NCF. Next, the behavior of the EERs of the fingerprint templates is also investigated in case of Fig.5, that is, same set of the transforms' orders for different fingers. Finally, the appropriate generation condition of the templates would be indicated.

5.1. In case of different sets of transforms' orders for different fingers

Table 2 shows the result for various ranges of the transforms' orders. The order of zero was excluded because it corresponds to no transform for the original fingerprint image. From this tables, it is found that the values of the EERs of the fingerprint templates are fully smaller than that (i.e., 2.45%) of the original fingerprint images. This means that the proposed fingerprint templates have much higher recognition accuracy than that of the original fingerprint images. In particular, it is understood that the EER has the smallest value, i.e., the orders of 10^{-7}, in case of the DFCT and the DFST when the ranges of the transforms' orders are $0.0< p_i \leq 0.3$ and $0.0< p_i \leq 0.5$.

Table 2. EERs(%) for the proposed fingerprint templates in case of different sets of the tramsforms' orders for different fingers

	DFCT	DFST
$0.0< p_i \leq 1.0$	4.59×10^{-4}	4.96×10^{-4}
$0.1\leq p_i \leq 1.0$	1.01×10^{-3}	9.94×10^{-4}
$0.3\leq p_i \leq 1.0$	8.51×10^{-3}	9.23×10^{-3}
$0.5\leq p_i \leq 1.0$	9.37×10^{-2}	9.45×10^{-2}
$0.7\leq p_i \leq 1.0$	1.88	1.92
$0.0< p_i \leq 0.1$	1.73×10^{-6}	1.81×10^{-6}
$0.0< p_i \leq 0.3$	5.17×10^{-7}	5.63×10^{-7}
$0.0< p_i \leq 0.5$	6.78×10^{-7}	4.58×10^{-7}
$0.0< p_i \leq 0.7$	4.32×10^{-6}	4.17×10^{-6}

5.2. In case of same set of transforms' orders for different fingers

In the previous subsection, a set of the transforms' orders was changed for each different finger, i.e., person to person. This means that each person needs an IC card or something where the information about the set was recorded, when the recognition or the enrollment is conducted. However, such an IC card had better not be used to make use of a merit of biometrics. Therefore, the EER is investigated in the case that only one set of transforms' orders is used for different fingers. In this case, the information about the set could be installed in the recognition or enrollment system.

Table 3 shows the result. From this tables, it is found that the values of the EERs of the fingerprint templates have almost the same order as that (i.e., 2.45%) of the original fingerprint images. This means that the proposed fingerprint templates have almost the same recognition accuracy as that of the original fingerprint images. In particular, it is understood that the EER has the smallest value (i.e., 3.81%) in the case of the DFCT when $0.0< p_i \leq 0.3$. Because this value is a little bit larger than that of the original fingerprint images, the method for minimizing the EER should be considered.

Table 3. EERs(%) for the proposed fingerprint templates in case of same set of the tramsforms' orders for different fingers

	DFCT	DFST
$0.0< p_i \leq 1.0$	4.57	4.57
$0.1\leq p_i \leq 1.0$	4.78	4.69
$0.3\leq p_i \leq 1.0$	5.18	5.11
$0.5\leq p_i \leq 1.0$	5.87	5.94
$0.7\leq p_i \leq 1.0$	7.25	7.16
$0.0< p_i \leq 0.1$	3.94	3.95
$0.0< p_i \leq 0.3$	3.81	3.90
$0.0< p_i \leq 0.5$	3.85	3.83
$0.0< p_i \leq 0.7$	3.83	3.88

6. Robustness of proposed fingerprint templates

The robustness of the proposed fingerprint templates was analyzed by use of the PSNR between the extracted (and aligned) fingerprint image and the inverse-transformed image of the fingerprint template. The inverse-transformed image was obtained under the condition that inverse transform's order was the same as the transform's one in each transverse line.

Fig. 6 shows the examples of the inversed-transformed images of the proposed templates shown in Figs. 3(a) and 3(b) and the PSNRs are 5.98dB and

5.96dB, respectively. Therefore, it is found that the proposed fingerprint templates have high robustness.

(a) (b)

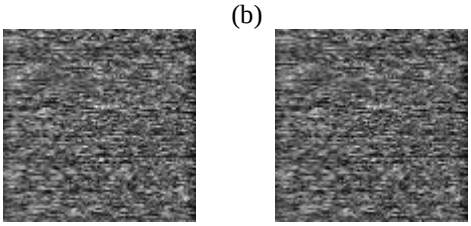

Figure 6. Examples of the inversed-transformed images of the proposed templates shown in Figs. 3(a) and 3(b)

In order to evaluate the robustness of the proposed fingerprint templates quantitatively, the averaged PSNRs were calculated for the proposed fingerprint templates, i.e., 557 PDs of the DFCTs and 557 PDs of the DFSTs, when the range of the transforms' orders was $0.0<p_i\leq 0.3$, in case of different sets of p_i for different fingers. As a result, the averaged PSNRs of the PDs of the DFCTs and DFSTs became 5.98dB and 5.99dB, respectively.

The averaged PSNRs were also calculated in case of only one set of p_i for different fingers. As a result, the averaged PSNRs of the PDs of the DFCTs and DFSTs became the same value of 6.02dB.

Therefore, it is understood that the proposed fingerprint template could not be easily restored to the extracted (and aligned) fingerprint images even if the information about the transforms' orders is used. In this way, we can say that the proposed fingerprint templates have fully high robustness.

7. Conclusions

In this paper, the fingerprint templates generated by the DFCT and the DFST have been evaluated. Specifically, the generated fingerprint templates corresponded to the PDs of the 1D DFCTs and DFSTs with different transforms' orders for the grayscale distributions in different transverse lines of the extracted (and aligned) fingerprint image. In particular, the cases of different sets of the transforms' orders for different persons and only one set of the transforms' orders for different persons were compared to each other from the viewpoint of the EERs based on the PV of the NCF.

As a result, it has been found that the appropriate condition is $0.0< p_i \leq 0.3$ and $0.0< p_i \leq 0.5$ in case of different sets of the transforms' orders for different persons. The order of the EERs is 10^{-7} for PDs of the DFCTs and the DFSTs and fully smaller that (2.45%) of the original fingerprint images. However, in case of only one set of the transforms' orders for different persons, the minimum EER is 3.81% for PDs of the DFCTs when $0.0< p_i \leq 0.3$ and a little bit larger than that of the original fingerprint images. In addition, the robustness related to the security of the generated templates is fully high, i.e., the PSNR is an order of several dB, for both of the two cases.

As a further study, how to minimize the EER without using the IC card should be considered well, for example, by generating a set of the transforms' orders based on the information about the fingerprint's minutiae of each person.

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