

Completely Contactless and Online Finger Knuckle Identification

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1 Abstract

2 Introduction

3 Matching Contactless Finger Knuckle

One of our contributions is the online finger knuckle identification. In this kind of situation, we choose the RFNet [13] as our feature extraction backbone, because the model not only is lightweight enough, but it achieves state-of-the-art performance on the palmprint dataset. Meanwhile, the paper [13] uses the soft-shifted triplet loss function, called SSTL to train the model and matching two features for dealing with translation problem. However, in generally, feature maps of the same class will not only just shift along two axes, but also will have local deformable transformation. For solving it, we propose a new loss and also a new matching method, called translation and rotation triplet loss function (TRTL). With the TRTL, the feature maps can be translated along the x-axis and y-axis, and can be rotated clockwise and counterclockwise. Then we will get the minimal value after translation and rotation as the similarity scores.

3.1 Translated and Rotated Triplet Loss Function

As for a new loss function, the most important point is whether it can be differentiable. With a differentiable loss, the back propagation process can proceed smoothly, and the learnable parameters can be updated to get the minimal loss. In this section, we will discuss the derivation of the TRTL loss function. Because our neural networks were trained using the architecture of triplet network [19], we used TRTL as loss function to update convolutional kernel of our models.

In generally, the TRTLoss is still a variant of triple loss, so that the TRTLoss can be written as a format of triple loss function as the Equation 1. As for the N , it means the batch size during training iteration, and $T(I^a)$ is the output template of input anchor image I^a through neural network. The hard margin parameter m can determine the distance between different class cluster by pushing them away during training process.

$$TRTL = \frac{1}{N} \sum_i^N [L(T(I_i^a), T(I_i^p)) - L(T(I_i^a), T(I_i^n)) + m]_+ \quad (1)$$

In order to adapt to tasks with different degrees of deformation, and balance performance and speed, we set translation and rotation ranges as a hyperparameter. The $L(T_1, T_2)$ will get the minimal distance of two templates $D_{w,h,\theta}(T_1, T_2)$ after translation and rotation in the range $-W \leq w \leq W, -H \leq h \leq H, -\Theta \leq \theta \leq \Theta$, called minimal translation and rotation distance (MTRD). Meanwhile, the distance $D_{w,h,\theta}(T_1, T_2)$ calculates the pixel-wise MSE value when template T_1 is translated w pixel along x-axis and h pixel along y-axis and rotated θ angle in the Equation 3.

$$L(T_1, T_2) = \min_{-W \leq w \leq W, -H \leq h \leq H, -\Theta \leq \theta \leq \Theta} D_{w,h,\theta}(T_1, T_2) \quad (2)$$

$$D_{w,h,\theta}(T_1, T_2) = \frac{1}{|C_{w,h,\theta}|} \sum_{(x,y) \in C_{w,h,\theta}} (T_1^{(w,h,\theta)}[x,y] - T_2[x,y])^2 \quad (3)$$

In terms of $C_{w,h,\theta}$, it represents the common region between two templates after one template shifted along x-axis with w , shifted along y-axis with h , and rotated with θ . As for the (T_a, T_p) pair, we can assume when the T_a is rotated angle of θ_{ap} and shifted with (w_{ap}, h_{ap}) pixels can get the minimal $D_{w_{ap},h_{ap},\theta_{ap}}(T_a, T_p)$, then $L(T_a, T_p) = D_{w_{ap},h_{ap},\theta_{ap}}(T_a, T_p)$. Meanwhile, with the $(w_{an}, h_{an}, \theta_{an})$, the (T_a, T_n) pair can get the minimal $D_{w_{an},h_{an},\theta_{an}}(T_a, T_m)$.

$$\frac{\partial Loss}{\partial T_i^p} = \begin{cases} 0, if(x, y) \notin C_{w_{ap},h_{ap},\theta_{ap}} or Loss = 0 \\ \frac{-2(T_i^a[[x_{w_{ap}}, y_{h_{ap}}]*M(\theta_{ap})] - T_i^p[x,y])}{N|C_{w_{ap},h_{ap},\theta_{ap}}|}, otherwise \end{cases} \quad (4)$$

The $M(\theta_{ap})$ is the rotation matrix.

$$\frac{\partial Loss}{\partial T_i^n} = \begin{cases} 0, if(x, y) \notin C_{w_{an},h_{an},\theta_{an}} or Loss = 0 \\ \frac{-2(T_i^a[[x_{w_{an}}, y_{h_{an}}]*M(\theta_{an})] - T_i^n[x,y])}{N|C_{w_{an},h_{an},\theta_{an}}|}, otherwise \end{cases} \quad (5)$$

As for the $T_i^a[x, y]$ derivation, because we shift and rotate the anchor in the above formula, we can inversely shift and rotate the positive and negative input feature.

$$\frac{\partial Loss}{\partial T_i^a[x, y]} = -\frac{\frac{\partial Loss}{\partial T_i^p[[x - w_{ap}, y - h_{ap}] * M(-\theta_{ap})]} + \frac{\partial Loss}{\partial T_i^n[[x - w_{an}, y - h_{an}] * M(-\theta_{an})]}}{N|C_{w_{ap},h_{ap},\theta_{ap}}|} \quad (6)$$

4 Experiments and Results

We choose the baseline model is the RFNet [13], its performance can outperform DenseNet-BC [9], CompCode [11], DoN [34], Ordinal Code [21], and RLOC [10] algorithms on the palmprint verification problem. For proving TRTL loss function performance, we will compare its performance with Soft-Shift Triplet (STTL)[13] loss function on different public finger knuckle database based on the RFNet [13]. With TRTL loss function, the RFNet is represented

by RFNet-TRTL, on the country, RFNet-STTL represents with STTL loss function. Compare to convolution layer or dilated convolution [32], the deformable convolution [35] can solve local deformable by sampling different location and different weight. We also replace the RFNet convolution layer with deformable convolution layer called DeConvRFNet. As for the RFNet and DeConvRFNet, we will firstly pretrain on the HKPolyU Finger Knuckle Images Database (V1.0) [24] as the pretrained weights.

Meanwhile, we will also compare with the FKNet [3] which get the state-of-the-art performance on 3D finger knuckle identification, and EfficientNetV2-S [22]. FKNet performance on the 3D finger knuckle database, 2D finger knuckle and even palmprint database can over SGD [2], CR_L1_DALM, CR_L2 [33], ResNet-50 [6], VGG-16 [20], AlexNet [12], DenseNet-121 [9], and SE-ResNet-50 [8]. Both of FKNet and EfficientNetV2-S are classification neural network. As a classification neural network, it commonly has a problem when the number of classes of testing dataset is not as same as the training set classes, result in fine-tuning on the testing set. Therefore, we use the vector before soft-max layer as the feature vector, and then calculate the MSE of two feature vectors as the similarity score during matching finger knuckle. We use the ResNet-50 pretrained weights as the FKNet initial weights, and use the pretrained weights on the ImageNet21K as the initial weights of EfficientNetV2-S.

We also want to show the performance of TRTL and STTL on the EfficientNetV2-S model, therefore we keep the same architecture and just change the FC layer of the head part with convolution layer for fitting TRTL and STTL. The changed EfficientNetV2-S model with TRTL called EfficientNetV2-S-TRTL, and with STTL called EfficientNetV2-S-STTL. As same as the EfficientNetV2-S model, we also use the pretrained model weights on the ImageNet21K dataset. In generally, public finger knuckle database already offer segmented finger knuckle images, but we use our YOLOv5-CSL model to segment finger knuckle as our training and testing data during our experiment.

4.1 Model Complexity Analysis

As a completely contactless and online finger knuckle identification, we must choose a model that can meet the requirements of matching speed while ensuring matching accuracy, and even sacrifice matching accuracy for a certain matching speed. We have listed learnable weights of each model, and the corresponding feature extraction time and matching time on the Table 1.

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4.2 Within Database Performance Evaluation

4.2.1 Contactless Finger Knuckle Image Database (Version 3.0)

The finger knuckle database [25] can offer contactless finger knuckle of 221 subjects, but only 104 subjects have second session samples. For each session, each subject can offer 6 samples. It is worth mentioning that the finger knuckle sample provided by this database is more challenging and closer to real world scenarios, because the finger knuckle will bend from 0 to 90 degree result in crease deformation.

One-Session Protocol

As for the one-session protocol, I firstly fine-tuned models on the second session 104 subjects

Model	Prams (M)	Input Size	Template Size	FLOPs (B)	Feature Extraction (s)	Matching (s)
DeConvRFNet-STTL	0.36M	128x128	32x32	1.29B		
DeConvRFNet-TRTL	0.36M	128x128	32x32	1.29B		
EfficientNetV2-S [22]	20.18M	300x300	classes	5.40B		
EfficientNetV2-S-STTL	20.00M	300x300	9x9	5.38B		
EfficientNetV2-S-TRTL	20.00M	300x300	9x9	5.38B		
FKNet [3]	7.28M	96x64	classes	0.28B		
RFNet-STTL [13]	0.46M	128x128	32x32	1.39B	0.0062s	0.049s
RFNet-TRTL	0.46M	128x128	32x32	1.39B	0.0062s	

Table 1: Comparison time and space complexity of different neural network. Time complexity is the average time of 10k images on the Ubuntu 22.04 with GeForce RTX 2080 GPU. When the template size is classes, it means the training set classes number.

dataset, totally $104 * 6 = 624$ images as the testing set. Then use the first session 221 subjects as the testing set result in $221 * 6 = 1326$ genuine matching scores and $221 * 220 * 6 = 291720$ imposter matching scores. From the Figure 1, we can easily find the RFNet is the best model not only on the ROC but also on the CMC. In terms of the baseline model RFNet, our loss function TRTL can improve the matching accuracy when compare to the STTL loss function. Although the finger knuckle of the database with deformation while bend from 0 to 90 degree, the EER of the RFNet-TRTL can arrive at 2.21%. And as top-2 ranking, the RFNet-TRTL recognition rate is about 0.97 on the CMC. As for the rest model, EfficientNetV2-S model performance is better than FKNet and DeConvRFNet. From the performance result, if we just change the convolution layer with deformable convolution, it cannot overcome finger knuckle deformation, even the performance is dropped.

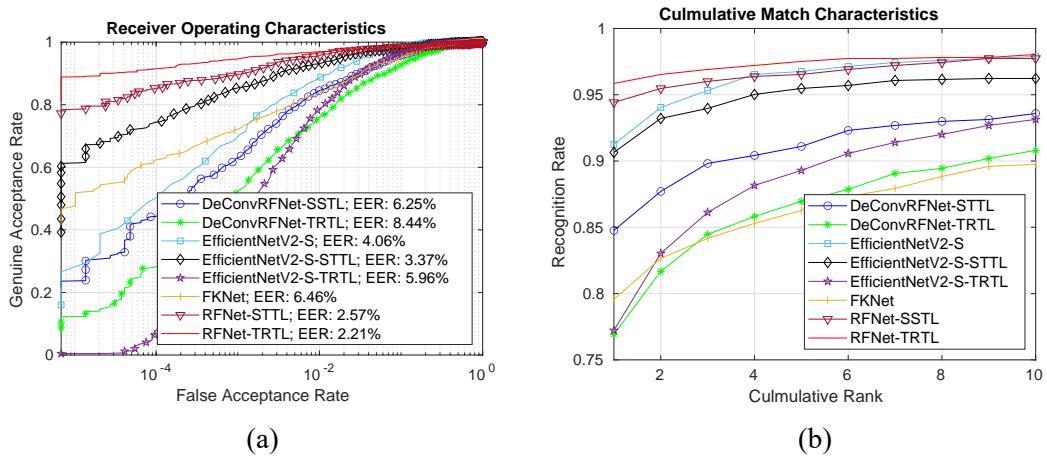


Figure 1: Comparative ROC (a) and corresponding CMC (b) for one-session on the contactless finger knuckle image database [25].

Two-Session Protocol

We fine-tune models on the first session subjects who don't provide second session samples, and use two-session protocol to evaluate my model performance on the first session subjects who can offer two-session data. In totally, it will generate $104 * 6 = 624$ genuine scores, and $104 * 103 * 6$ imposter scores. Just like said before, the FKNet and EfficientNetV2-S are classification

networks, we use output feature vector to calculate MSE as the matching score. Because the degree of deformation vary on the two-session data, the verification and identification scenarios is more complexity than one-session protocol. Due to these factors, the accuracy on the two-session protocol is much lower than the one-session protocol. However, the RFNet is still the best model, even its EER is half of the EER of other models. Meanwhile, our TRTL loss function still work better than the STTL loss function, with 16.65% and 18.35% respectively on the ROC. As for the CMC, when the cumulative rank value is 2, recognition rate of RFNet-TRTL can arrive at 0.7. From the ROC and CMC Figure 2, we can also get that the STTL and TRTL triplet loss function are better than classification task, because the FKNet and EfficientNetV2-S have the lowest accuracy.

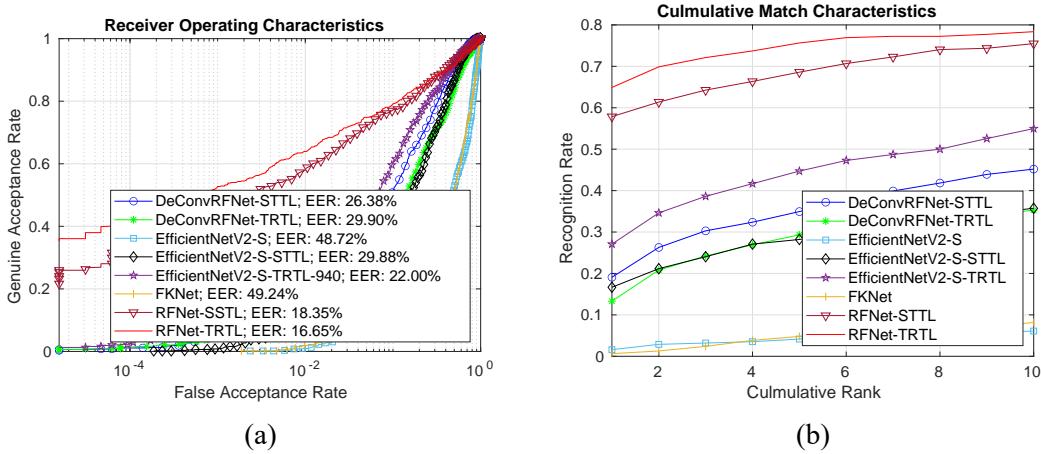


Figure 2: Comparative ROC (a) and corresponding CMC (b) for two-session on the contactless finger knuckle image database [25].

4.2.2 Index Finger Knuckle of Contactless Hand Dorsal Image Database

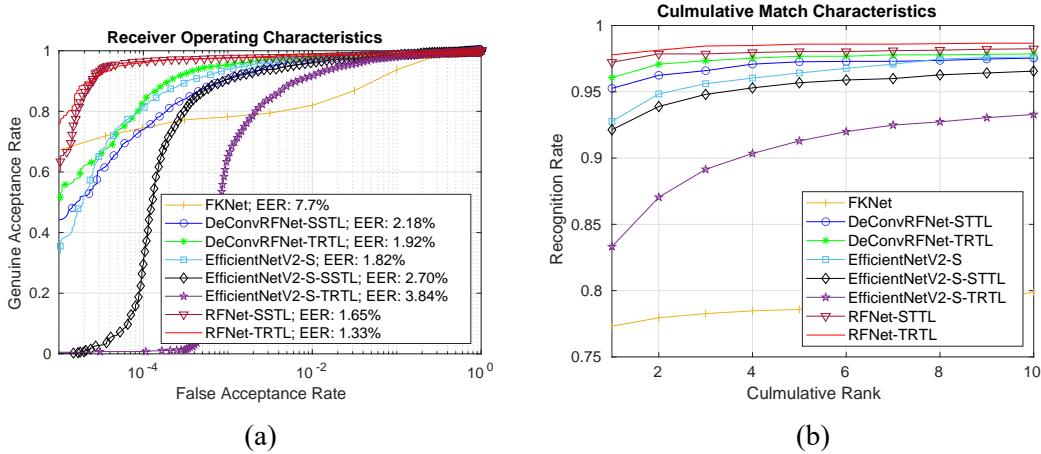


Figure 3: Comparative ROC (a) and corresponding CMC (b) for one-session on the contactless hand dorsal image database [26].

As for the experiment, the dataset [26] totally contains 712 subjects, and each subject have 5 finger knuckle samples. And we fine-tuned our models on the first sample of each subject, and then use the rest four sample as the testing dataset. For protocol on the database, we use protocol

as same as protocol of the FKNet [3]. At the evaluation process, it has $712 * 4 = 2848$ genuine matching scores, and has $712 * 711 * 4 = 2024928$ imposter matching scores. The performance of RFNet-TRTL and RFNet-STTL is similar, but the RFNet-TRTL is slightly better than RFNet-STTL depend on the EER value on ROC. And on the CMC, the RFNet-TRTL still get the best accuracy. We can notice that the FKNet get the worst result when compare to other models. The EfficientNetV2-S model is still better than the FKNet, because EfficientNetV2-S is deeper than FKNet with MBConv block. MBConv block is more robust than the original residual block.

4.2.3 2D Forefinger of 3D Finger Knuckle Database

The HKPolyU 3D Finger Knuckle Images Database [23] can offer reliable 3D finger knuckle pattern (surface normal vector, depth, or curvature) from 2D finger knuckle images, therefore we use its 2D images as our evaluation database. 190 subjects of the database have two-session finger knuckle samples, and 38 subjects offer one-session images. In this kind of situation, two-session protocol is not fit on the database, then we use one-session protocol to evaluate performance. We use the first session 190 subjects images to fine-tune models and then to test on the second session 190 subjects. It has $190 * 6 = 1140$ genuine matching scores and $190 * 189 * 6 = 215460$ imposter matching scores. From the ROC and CMC, we can get a conclusion that the performance of RFNet, DeConvRFNet, and EfficientNetV2-S are similar. However, the FKNet is still the worst one, which EER is 5.74% and the CMC is lower than others. The unchanged thing is that the RFNet with TRTL loss still get the best performance with 1.60% EER, even for the recognition rate on the CMC.

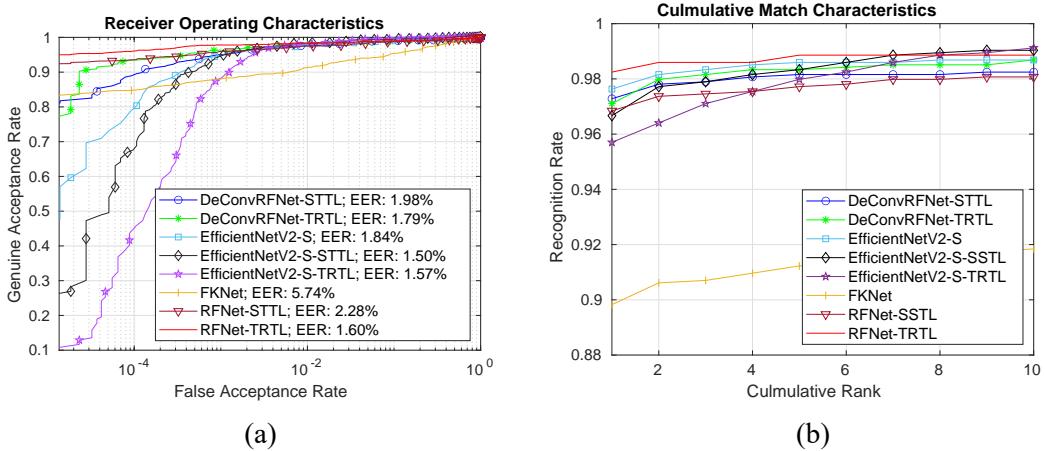


Figure 4: Comparative ROC (a) and corresponding CMC (b) for one-session on the 3D finger knuckle database[23].

4.3 Cross Database Performance Evaluation

From the within database experiment, we can clearly get a conclusion that the TRTL loss function can increase the performance compare to the STTL loss function, and the RFNet is better than the DeConvRFNet, EfficientNetV2-S, and FKNet. Meanwhile, the FKNet performance is the worst one. In this section, we will compare these models' performance on the cross database experiment. For these cross database experiment, it can get the generalization ability of neural network, because these data can be regard as unseen data.

As for the cross database experiment, I firstly pre-trained our models on the Finger Knuckle Images Database V1, and then fine-tuned models on the Finger Knuckle Images Database V3 (with deformation). In the next step, we use our models to test all the finger knuckle of the Hand Dorsal Images Database and the Tsinghua Finger Vein and Finger Dorsal Texture Database (THU-FVFDT3) [27]. Although the THU-FVFDT3 database can offer two-session samples with interval several seconds, but strictly speaking, it is not two-session database. Therefore, I just use the training set of the database (THU-FVFDT-FDT3_Train) as our evaluation dataset.

4.3.1 Hand Dorsal Images Database

Index Finger Knuckle and Middle Finger Knuckle

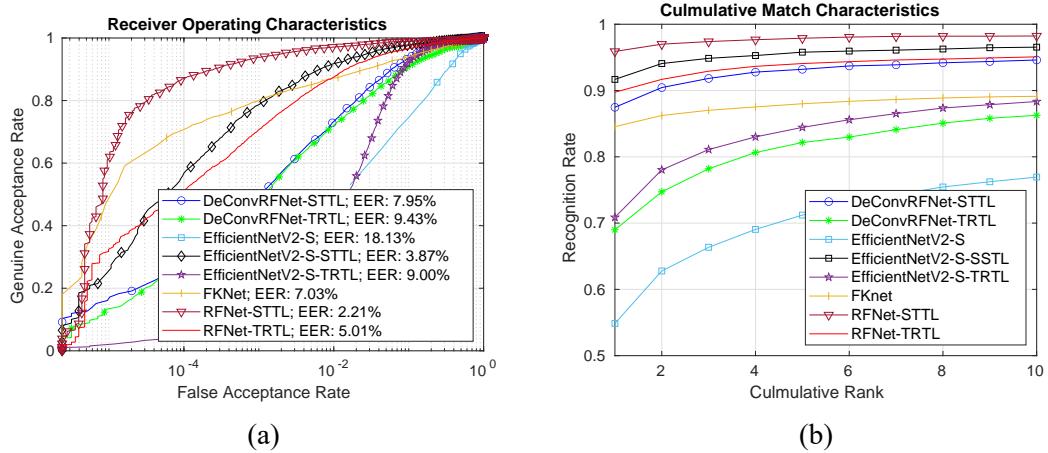


Figure 5: Comparative ROC (a) and corresponding CMC (b) for one-session of the index finger knuckle on the contactless hand dorsal image database [26].

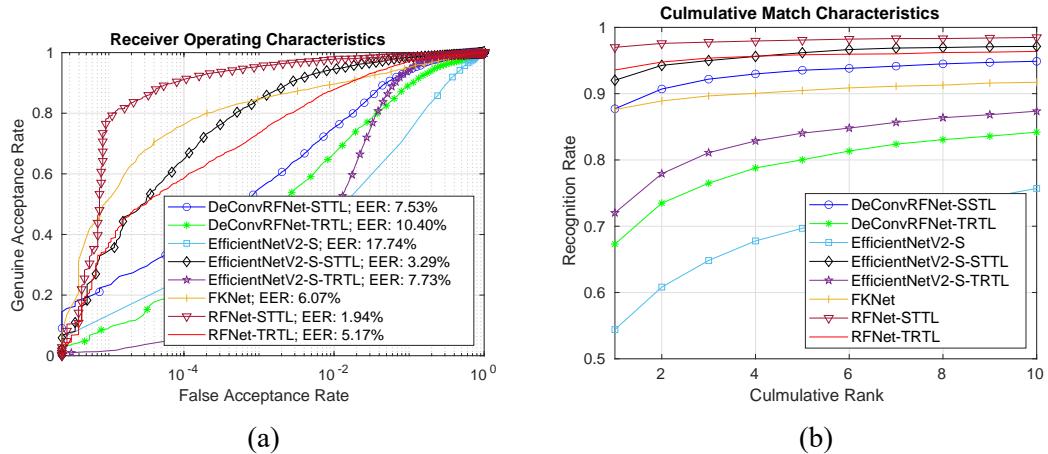


Figure 6: Comparative ROC (a) and corresponding CMC (b) for one-session of the middle finger knuckle on the contactless hand dorsal image database [26].

The database totally has 712 subjects, and each subject has 5 samples of hand dorsal image. Therefore, it will have $712 * 5 = 3560$ genuine matching scores and $712 * 711 * 5 = 2531160$ imposter matching scores for index and middle finger knuckle. Figure 5 is the performance result on the index finger, and Figure 6 is the performance result on the middle finger knuckle.

From Figure 5 and Figure 6, all models' cross database performance is similar on the database regardless which finger. We should also notice that STTL is better than TRTL on the cross database experiment, while within database, the TRTL is better than STTL. It shows that the generalization ability of TRTL is not better than STTL to some extent. However, the RFNet-STTL outperform the rest models depend on the ROC and CMC. Even better than FKNet and EfficientNetV2-S, both of them are classification models.

4.3.2 Tsinghua Finger Vein and Finger Dorsal Texture Database

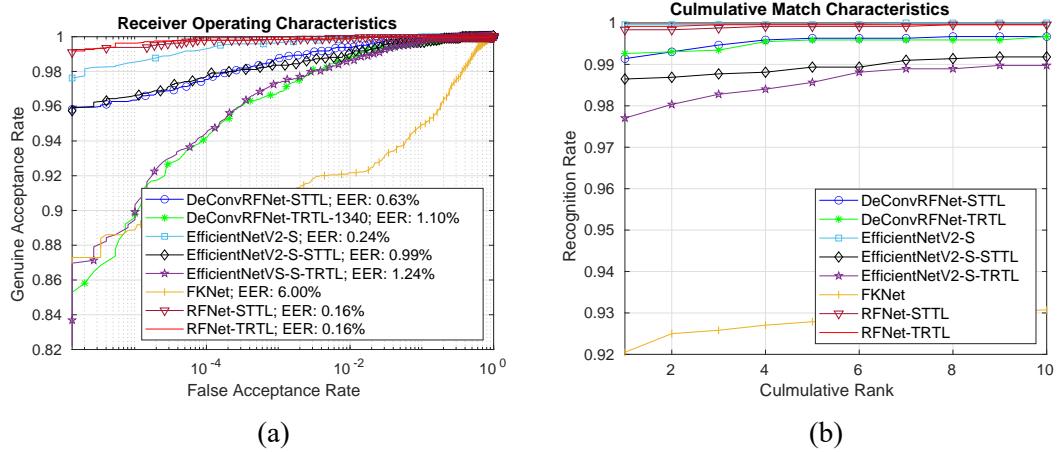


Figure 7: Comparative ROC (a) and corresponding CMC (b) for one-session of the finger dorsal texture images [27].

The database [27] has 610 subjects, and each subject can offer 4 samples. From the finger dorsal texture images, we can use our YOLOv5-CSL model to segment finger knuckle images as our testing set. Then as the cross database experiment, it will have $610 * 4 = 2440$ genuine matching scores and $610 * 609 * 4 = 1485960$ imposter matching scores. In this database, all models can get very high matching performance from the Figure 7, even the worst FKNet can arrive at 6.00% EER on the database. The RFNet with TRTL and STTL get the same accuracy, in terms of the CMC, the recognition rate almost arrive at 100%.

4.4 3D Finger Knuckle Images Database

The 3D finger knuckle images database [23] can offer robust 3D information which can be invariant to changed illuminations, for example, the depth information of the crease of finger knuckle. With the 3D finger knuckle database, the FKNet is the state-of-the-art. Meanwhile, RFNet with TRTL loss function can get the best performance on the within database experiments and cross database experiments when compare to the FKNet on the 2D finger knuckle database. Therefore, we compare the RFNet with FKNet on the database to show the identification performance on 3D finger knuckle database. As for the protocol, it will generate $190 * 6 = 1140$ genuine matching scores, and $190 * 189 * 6 = 215,460$ imposter matching scores from matching matrix. From the Figure 8, RFNet-TRTL still can get the best performance for finger knuckle verification and identification. Form the ROC curve, the EER of the RFNet-TRTL can increase to 1.05% while the EER of the FKNet is 2.4%. Not only on the 2D finger knuckle database, but

also on the 3D finger knuckle database, the RFNet-TRTL can outperform the state-of-the-art results.

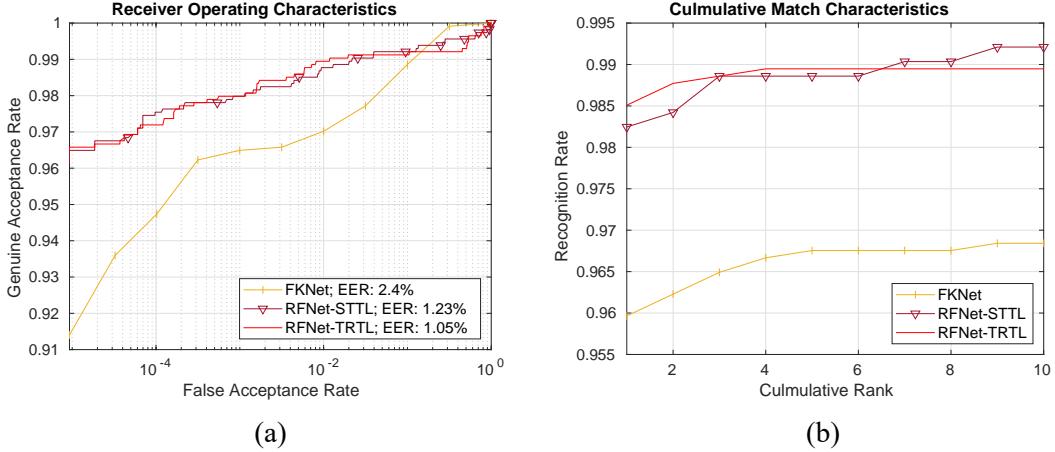


Figure 8: Comparative ROC (a) and corresponding CMC (b) for one-session of the 3D finger knuckle database [23].

4.5 Discussion

We have compared the identification performance of RFNet with EfficientNetV2-S, DeConvRFNet, and FKNet on the 2D and 3D finger knuckle database, and on the within database and cross database experiments. Due to deeply learned residual features of the RFNet which have already outperformed the state-of-the-art results on the palmprint, it still can get the best performance on the finger knuckle crease when compare to the rest models from above experiment results. Because finger knuckle is very prone to flexing, causing crease texture distortion, if just shift the template, it cannot solve the deformation problem with rotation. Therefore, we design our new TRTL to further solve the problem. With our TRTL loss function when train RFNet and MTRD when matching finger knuckle, the RFNet can increase matching accuracy regardless on the ROC and CMC based on the STTL. Especially on the Finger Knuckle Images Database (Version 3.0) which offer bending finger knuckle with complexity deformation, RFNet-TRTL improved performance is relatively more compare to other database from the Figure 1 and Figure 2. Two-session protocol is more complexity because of changing finger knuckle crease and more complexity deformation when matching process. Form the Figure 2 (a) ROC and (b) CMC, our TRTL with RFNet get the best matching and recognition performance. Meanwhile, our TRTL not only work on the RFNet, but also can work on the DeConvRFNet from the Figure 3 and Figure 4, with TRTL loss function, the matching and recognition performance also can increase.

From these experiment results, we can also get a conclusion is that EfficientV2-S model is better than FKNet from the within database experiment, and even on the Tsinghua finger knuckle database. EfficientNetV2 model can outperform the ResNet on the ImageNet [18], in other words, the EfficientNetV2 model can extract robust feature than ResNet on the ImageNet. Because EfficientNetV2 replace the residual block with inverted residual block, and use MBConv as a block unit. As for MBConv block, it uses depth-wise convolutions to decrease training weights and use Squeeze-Excited block as channel attention. Meanwhile, the depth of EfficientNetV2-S is deeper than the FKNet. On the contrary, the FKNet use the ResNet-50

fist conv3 as the feature extract model. EfficientNetV2 use the more light, advance and efficient module than ResNet.

However, TRTL generalization ability is lower than STTL loss from the cross database experiment, except on the Tsinghua database. On the cross hand dorsal database, Figure 5 and 6, EER of RFNet with TRTL performance will drop from about 2.0% to 5.0%. As for the rest model, performance with TRTL also drop with corresponding value when compare to STTL. But in the within database experiment, these model with TRTL loss is better than STTL loss. It shows our TRTL can affect the back propagation during training process to the different model weights, in other words. And another phenomenon is that EfficientNetV2-S with SSTL and TRTL cannot work. From the Table 1, if the input image size is 300x300, EfficientNetV2-S with STTL and TRTL will output 9x9 template size. The output feature size is too small when use the STTL and TRTL loss function, inversely, the performance will drop while translation and rotation.

4.6 Ablation Study

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5 Online Contactless Finger Knuckle Identification

With TRTL loss, the RFNet [13] can outperform state-of-the-art methods. In the previous section, we have estimated its verification and identification performance on different public finger knuckle database, including within-db and cross-db experiments. As for a completely contactless and online finger knuckle identification, the finger knuckle detector is a very important module for automatically detect and segment finger knuckle region. However, as for traditional segmentation algorithm, they cannot correctly segment the finger knuckles in the presence of complex background interference, multiple finger knuckles in the same field of view, obscured finger knuckles or bent finger knuckles. Meanwhile, as for neural network, the current based on YOLO [16], [14], [15], [1], [28] and R-CNN [5], [4], [17], [7] series object detection and segmentation approaches cannot simultaneously obtain the angle of finger knuckle and the segmentation with high precision. Especially, the angle of the finger knuckle is a vital factor for identification. If we can get the angle of finger knuckle, we can use angle information to align two feature maps for increasing matching accuracy and efficiency. For solving above problems, we propose rotated bounding box detection based on YOLOv5 model for segmenting and getting angle information.

5.1 Contactless Finger Knuckle Detection

5.1.1 Rotated Bounding Box Based on YOLOv5

In order to solve the problem of finger knuckle detection in the real world, we choose to use YOLOv5 model because the YOLO series is famous for its fast detection speed and high accuracy. Especially, the YOLOv5's [28] speed can meet our online detection requirements.

Rotated Bounding Box

However, the YOLOv5 just detect horizontal bounding boxes which cannot offer angle information and will segment a lot of background information. In order to solve these above problem, a rotated bounding box will be predicted instead of horizontal bounding box. As analyzed in this paper [31], the rotated bounding boxes loss will mainly come from angular periodicity and the exchangeability of edges. When use the long side definition of rotated bounding box, it can deal with the exchangeability of edges problem. Meanwhile, using classification task to predict angle can make model easier to train. A periodic coding method called Circular Smooth Label (CSL) [31] soft coding can also solve the problem that One-Hot cannot distinguish class relationship. Formula 7 $g(x)$ is the window function to smooth One-Hot label, and r is a window function of the radius.

$$CSL(x) = \begin{cases} g(x), & \theta - r < x < r + \theta \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

Furthermore, in this paper, we used the Gaussian function for the Equation 7 window function, a commonly available function, and used a window radius of 6 to smooth the labels.

Loss function

The original YOLOv5 loss function can have three components. The formula can be simply written as $Loss = CIOU_Loss + Loss_{conf} + Loss_{class}$. Since the rotated bounding box is based on the modification of YOLOv5, only the angle classification loss is added more. So the total loss function is as expressed in Equation 8, with the addition of $Loss_{angle}$ to YOLOv5 loss function.

$$Loss = CIOU_Loss + Loss_{conf} + Loss_{class} + Loss_{angle} \quad (8)$$

$$Loss_{angle} = \sum_{i=0}^{S^2} I_{ij}^{obj} \sum_{a \in [0, 180)} [\hat{P_i}(a) \log(P_i(a)) + (1 - \hat{P_i}(a)) \log(1 - P_i(a))] \quad (9)$$

5.1.2 Contactless Finger Knuckle Dataset

Our task is to detect finger knuckles in the contactless and online scenario, but by understanding current public finger knuckle database, their data are collected at specific conditions such as certain angle, certain light. In this kind of situation, this kind of data cannot represent real images of finger knuckle in real world. In order to address the shortcomings of current public finger knuckle dataset for contactless detection, we use a web crawler to get images from the Unsplash [29] where the keywords are finger knuckles. The Unsplash is an image site that offers uploads and downloads, and uses a copyright license that allows users to download and use them for free or even for commercial use [30]. We have downloaded 2347 images, there are 738 images without knuckles, and these images can be used as background training, and the rest 1609 images that contain at least one finger knuckle are the positive samples for the network model. In the network training process, we use crawled images, 169 finger knuckle images from the HKPolyU Finger Knuckle Database (V1.0) [24], and 64 finger knuckles images from the HKPolyU Hand Dorsal Database [26] as for the training set. And we use the rest data as

testing set to evaluate performance. The most important part is the data augmentation which contains flip, rotation, resize, translate and mosaic.

5.1.3 Contactless Finger Knuckle Detection

Detection Performance

The YOLOv4 model predict horizontal bounding box, while the remaining YOLOv5 model predict rotated bounding box with CSL classification, called YOLOv5-CSL. We can see the performance difference between these variations of the YOLOv5 model from the Table 2. Among the downloaded 2580 images, 100 images were randomly selected as the testing set.

Model	Inference Time/ms (1024x1024)	Number of Layers	$mAP_{0.5}^{val}$	AP of Major FK	AP of Minor FK
YOLOv5x-CSL	41.395	407	89.9	89.6	90.1
YOLOv5m-CSL	36.252	263	85.7	88.9	80.4
YOLOv4	25.992	161	70.7	83.6	57.7

Table 2: Comparison of the accuracy of the different models of the YOLO series for the detection of the finger knuckle. The calculated values of mAP were measured at a detection threshold of 0.4 as well as an IOU threshold of 0.5.

Segmentation Performance

This section aim to compare quality of finger knuckle between YOLOv5-CSL segmented and dataset offered. Because the segmented finger knuckle on the 3D Finger Knuckle Dataset already have high quality, I mainly test on the Index Finger Knuckle of Hand Dorsal Dataset and the Finger Knuckle Dataset V3 (with deformable).

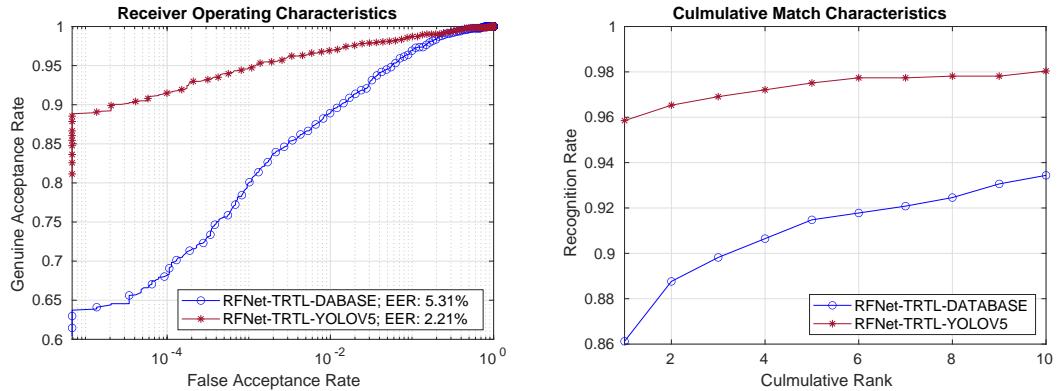


Figure 9: Compare performance on the Finger Knucle V3 Dataset (with deformable)

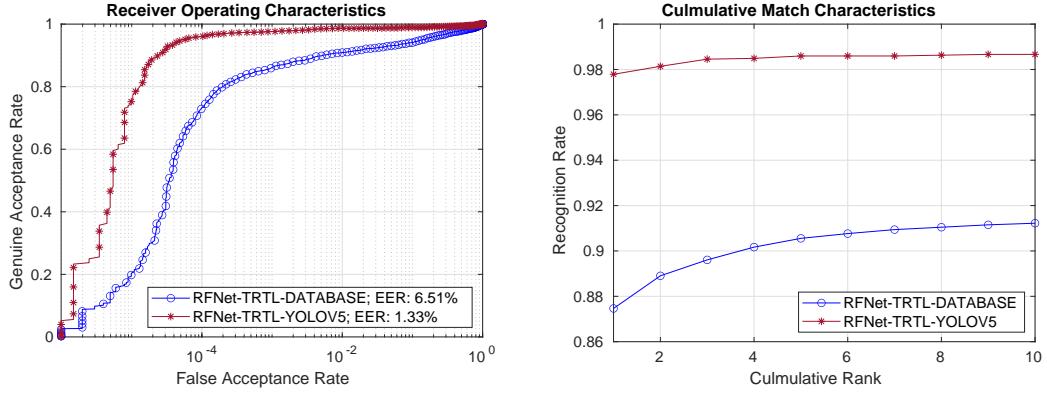


Figure 10: Compare performance on the Index Finger of the Hand Dorsal Image Database.

From the above figures, we can clearly get the conclusion that quality of segmented finger knuckle of YOLOv5 is better than the segmented finger knuckle of dataset through the ROC curve and CMC curve. Especially on the Hand Dorsal Image Database, the EER value can drop from 6.51% to 1.33%.

5.2 Online Contactless Finger Knuckle Identification Performance

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6 References

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