Composite Filter for Vanderlugt Correlator

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ABSTRACT

This paper examines the use of composite filters for improving the effectiveness of a Vanderlugt correlator when used for fingerprint identification. A digital simulation, which accounts for noise sources in the optical setup, is used to design and test composite matched spatial filters. Results are presented for a real time video image database containing 10 seconds of video from 200 fingers. Using the composite matched spatial filter the Vanderlugt correlator is getting 70% correct identifications with no false positives.

KEYWORDS: fingerprint, optical correlation, Vanderlugt correlator, spatial light modulator, composite matched spatial filter

1. INTRODUCTION

This paper discusses the use of a composite matched spatial filter (MSF) in a Vanderlugt correlator (VC) to improve fingerprint identification accuracy. Most current methods of optical fingerprint identification use a joint transform correlator (JTC) [1-3,8] with filtering of the joint power spectrum to improve identification accuracy. The VC for this experiment used a thermoplastic plate (TP) to record the MSF. The TP has better bandwidth than an electrically addressable SLM (EASLM), can be used with a higher resolution SLM at the input and is erasable.

Previous work[4] showed that using the MSF with only one input image resulted in poor correlation with a second image of the same fingerprint. The second image varied significantly due to ridge variations from the elasticity of the finger and changes in pressure when capturing the print. The optical correlator could not distinguish between the second image and other non-matched fingerprints. In this paper we discuss a method for correcting this problem using a composite MSF that records a sequence of the elastic variations into one MSF. This method appears very effective and has been used in over 50 laboratory demonstrations with no false matches with hundreds of non-matched prints tested. The composite MSF is still sensitive to rotation and large elastic deformations that can result in false negatives.

Results are presented for NIST Special Database 24[5] (SD24), a live-scan digital video fingerprint database and extra data not published in the original database release; a total of 200 test samples are used. The data contains two 10 second captures of 200 fingerprints from a live-scan fingerprint reader. The first 10 seconds of data had individuals making changes in pressure to create elastic distortions. This data was used to create the composite filter. The second 10 second capture had each individual rotate their finger through a set of angles to capture a set of rotated fingerprint data. Some of second 10 seconds was used for testing the composite filters.

The TP used in the optical setup does have a limited number of exposures and time consuming procedure for erasing, so to reduce cost and time a digital simulation is used in designing and testing the composite filters. The simulation incorporates noise caused by components of the optical correlator to provide realistic test results. After designing a composite MSF with the simulator, results from the simulation are compared to actual results verifying the accuracy of the simulation.

2. COMPOSITE MATCHED SPATIAL FILTER

The initial composite filter design used successfully in our laboratory was made by recording the MSF using ten seconds of continuous video input from a live-scan fingerprint reader. Further tests show that ten seconds may be more data than is needed for the MSF. The MSF discussed here will attempt to get the same results using less data for creation of the composite MSF.

Initial testing showed that making a MSF with only one fingerprint image on the VC failed to detect a second image of the finger taken at a later point in time under different conditions. The cause appeared to be the elasticity of the finger which deforms significantly under varying pressure. Figure 1 shows two images of the same captured at different times. The ridge spacing is stretched enough so the ridges are completely out of phase over most of the image The best solution, for the VC, is creating a composite MSF of the fingerprint while changing the pressure on the finger so that elastic distortions are recorded in the MSF. However, this method is still limited on the amount of distortion that is tolerable and currently is very sensitive to rotation.

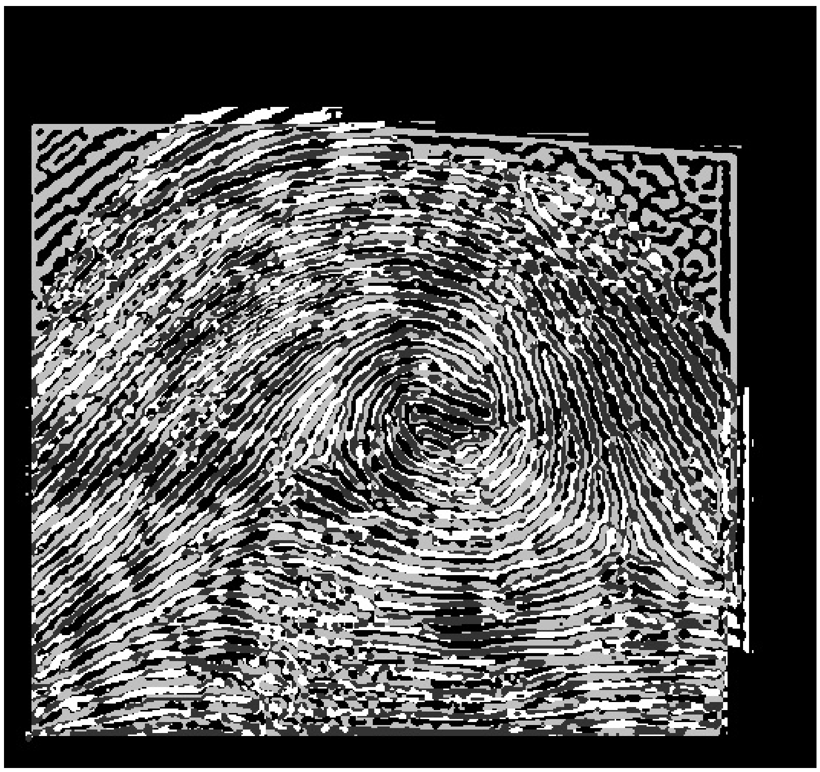


Figure 1: Elastic deformation between two fingerprints. White and light gray are ridges that do not correlate, dark gray show ridges that do correlate.

Figure 2 illustrates the VC setup used in the experiment. This VC setup was used in this experiment because of its large bandwidth (from the TP) which allows for high resolution input images. The critical alignment of the system is not a problem when using the TP to record the MSF. This material is erasable so that new filters can be made without moving any components in the system

A fingerprint is loaded on the input EASLM, a Kopin LVGA* (Video Graphics Adapter) SLM with 640x480 pixel resolution, and Fourier Transformed (FT) by a lens onto the thermoplastic plate with the reference beam on. Matching is achieved by placing a new pattern on the SLM with the reference beam off. The product of the MSF and the input pattern are

* Certain commercial equipment may be identified in order to adequately specify or describe the subject matter of this work. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the equipment identified is necessarily the best available for the purpose.

inverse Fourier Transformed (IFT) by a lens and the output correlation is displayed on CCD-1. Two additional CCD's are setup to monitor the Fourier Spectrum (CCD-2) and the input pattern (CCD-3) seen on the SLM. The input to the SLM for this experiment was a live-scan fingerprint reader that produced real-time National Television Standards Committee (NTSC) video which is sent through a NTSC to VGA converter into the SLM. There are hardware limitations with the SLM and it can not display at true video rates [6] but the performance is sufficient for this experiment.

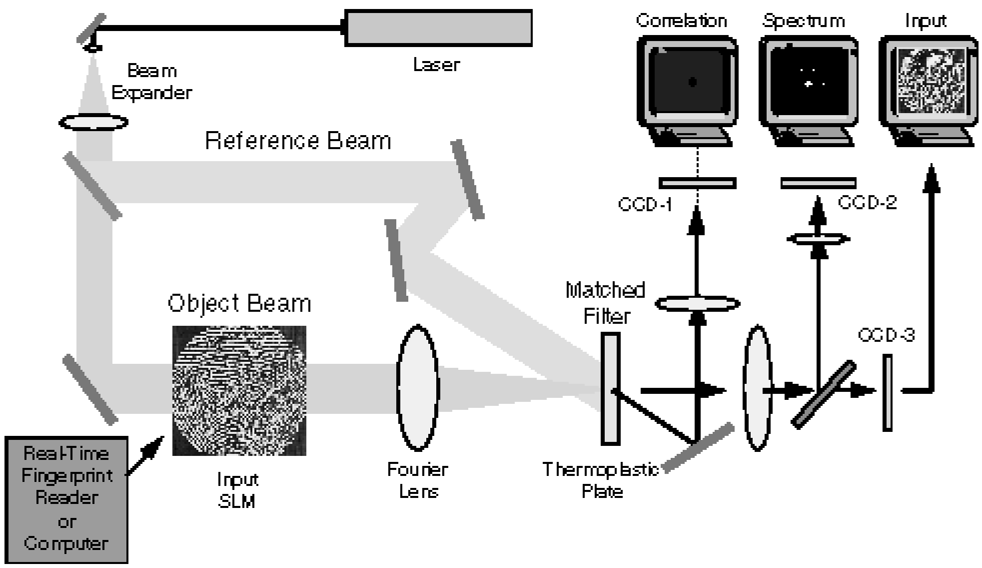


Figure 2: Diagram of Vaderlugt Correlator setup.

The initial composite filter was made by recording for ten seconds while a fingerprint was moved creating elastic distortions. It was critical that the fingerprint not be translated significantly during the recording as this would smear the MSF and it would not work as effectively when looking for a "matched peak". At this point no rotation is being added to the filter. The VC, with a live-scan fingerprint reader setup, makes filter creation very easy but the limited life span of the thermoplastic plate (several hundred exposures) makes it more practical to do initial testing and design with a digital simulator. While the VC works well with ten seconds of data, results show that the same results can be achieved with much less data; this may be useful for composite filters in JTC setups.

Since the test data on SD24 is ten seconds of digital video, a simple method for reducing the input filter data is to remove adjacent frames that do not offer significantly new information. The simplest digital method is to compute the mean squared error (MSE) of the adjacent frames and set a cutoff threshold to accept new data. This method works best starting with the first image in the sequence and successively comparing it to subsequent images until reaching the MSE threshold. The image is added to the composite filter and is the starting point for computing MSE until the threshold is reached. Using this method and an acceptable threshold value, a sequence of 300 images (10 seconds of digital video) can be reduced to about 7-10 images per MSF.

A problem with the SD24 data is that it was captured with only a few restraints on how the person moved their finger. This causes problems for making composite filters which need the core to remain in place. For this test, only data where the core was held in place was used in creating the composite filter so not all the data sets contained 300 frames of initial data. In fact, some only had 20 frames of useful data in sequence. This data was still used helping test the limits of how little data could be used for making the composite MSF.

3. DIGITAL SIMULATION

Because the TP in has a limited number of exposures and requires several steps to erase, designing and testing a composite MSF filter over a large data set could become rather expensive and time consuming. To speed this process, a digital simulation was used to design and test the composite MSF. The simulation was carefully designed to have much of the noise present in the actual optical setup, shown in figure 2. The SLM is the most significant source of noise in the system, contributing both amplitude and phase errors. A significant amount of work has been done modeling the SLM and the noise it adds to the system [7]. The results of this previous work was used to model the SLM in this simulation. Currently, a simpler method is used to measure noise caused by other system components. Black (0 pixel value) and white (255 pixel value) test images are input to the system and the resulting output is captured. The captured outputs for these test images are used along with the SLM model to modify the input data for the digital simulation. Figure 3 shows the results of SLM modeling, the two images show the non-flatness (I_m) the SLM adds to the image pixels as well as the phase errors (I_p) that occur do to the SLM. Figure 4 shows the output for the black (I_b) and white (I_w) test images. Figure 5 shows original fingerprint data before and after it is adjusted with the noise images shown in figures 3 and 4. The original data was adjusted using the following model where: k is a scaling factor, I is the input image, I_{mx} and I_{mn} are the maximum and minimum input pixel values, and I' is the adjusted image data used as input to the simulation.

$$I' = k * [((I/(I_{mx}-I_{mn}))(I_w-I_b)) + I_b]$$

$$\mathrm{RE}\{I'\} *= I_m$$
$$\mathrm{IM}\{I'\} += I_p$$

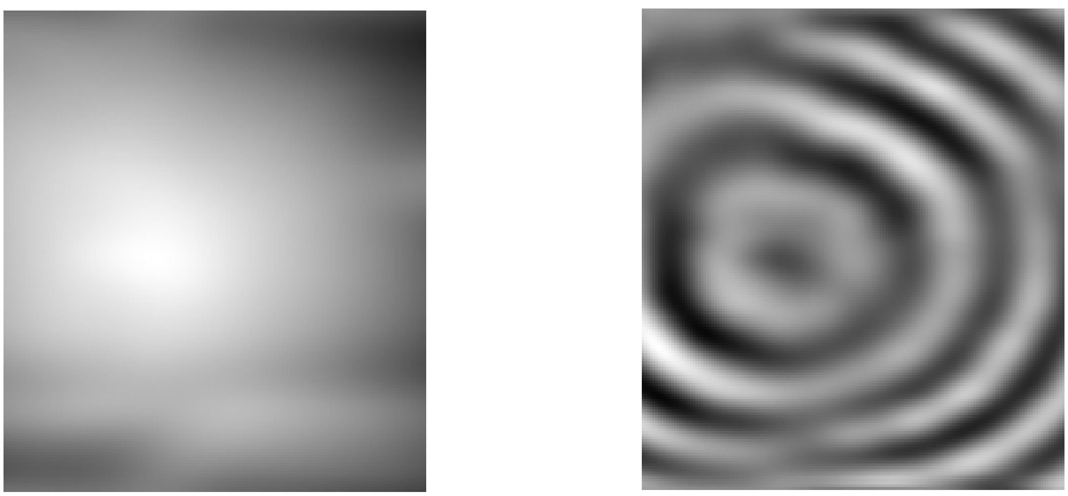


Figure 3: Non-flatness (I_m) and phase error (I_p) caused by SLM.

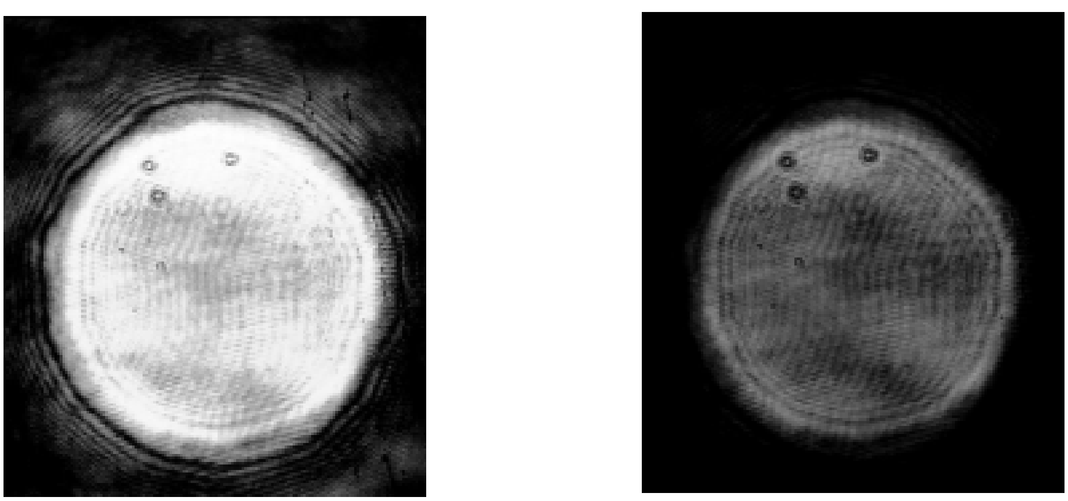


Figure 4: Output for white (I_w) and black (I_b) test images measuring component noise.

After adding noise to the input images, the rest of the simulation was straight forward. Each image in the composite MSF was Fourier Transformed and its complex conjugate summed into the filter. In the optical setup, discrimination capacity is increased by setting the k-ratio of the image and reference beams to allow higher frequency information to be more visible and the lowest frequencies near the DC value are saturated. Since an exact correlation between the real k-ratio and digital simulation is very difficult, this was done experimentally in the digital simulation. A clipping threshold was selected so the simulated composite MSF produced a similar saturation region and high frequency discrimination when compared to the experimental results.

$$\text{MSF} = \Sigma\,[\text{Clipping}(\text{FT}^{*}(I(x)^{'}))]$$

Correlation of the MSF with other fingerprints (I_n) is done by computing the product of the fingerprint's FFT and the composite MSF then IFFT the result.

$$\text{MSF} \circ I_n = \text{IFFT}^{-1}(\text{MSF} * \text{FFT}(I_n))$$

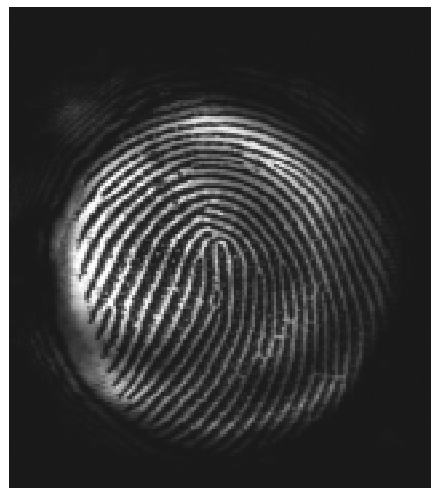
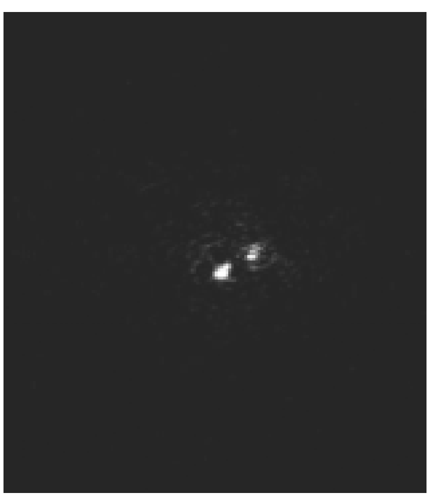


Figure 5: Input image before (I) and after adding noise ($I^{'}$).

After all the noise sources were taken into account, tests were performed with the simulator and the results compared to the experimental output from the optical bench. Figure 6 shows images from these test. After comparing the results and fine tuning some of the noise parameters and clipping threshold, the simulation was used to design and test the composite filter.



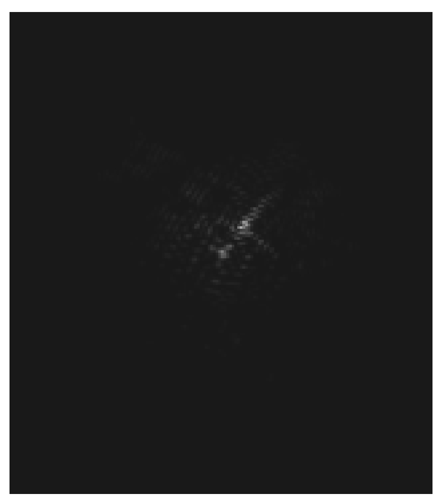


Figure 6: Actual (left) and simulated (right) correlation results.

4. RESULTS

SD24 and similar data (not published in the database do to CDROM data size limitations) was used for testing the composite filter. The data contained two 10 second captures of 200 fingerprints from a live-scan fingerprint reader. The first 10 seconds of data had individuals making changes in pressure to create elastic distortions. This data was used to create the composite filter. The second 10 second capture had each individual rotate their finger through a set of angles to capture a set of rotated fingerprint data. Selected images from the second 10 seconds were used to test the composite filters.

As discussed in section 2, the data was screened before creating the composite filters to remove translated and rotated data . After selecting non-translated/rotated data, composite filters were created for all 200 fingerprints from the first 10 seconds of scanned fingerprint data using the method previously discussed. The actual number of images used to create the composite filters range from 5-11 images.

Testing data was selected from the second 10 seconds of scanned fingerprint data. A single print was selected for each finger in the database resulting in a total of 200 test prints. The fingerprints selected for test data were chosen to eliminate rotation differences between the test print and the composite MSF. Future work will attempt to improve rotational tolerance; then, all the data will be used for testing. The 200 composite filters were correlated with all 200 test prints. So, out of the 40,000 comparisons made, there existed 200 correct identifications and 39,800 non-matches.

This VC setup correctly identified 70% of the fingerprints with 30% false negatives and 0% false positives. False negatives are when a system does not get a match for two fingers that are actually a match and false positives are getting a match when two fingerprints do not match. The false negatives resulted from one of three factors: low quality prints, rotation, or large elastic distortions. An advantage to VC system is that the input is live video from the fingerprint scanner. If an error is caused by rotation or elastic distortion, simply readjusting the print to remove the rotation or elastic distortion will give the correct match with little delay.

5. CONCLUSIONS

The VC is reliable for fingerprint identification when using a composite MSF. The VC, which uses all the information in the image, is a more stringent fingerprint matcher than minutiae based matchers which use a finite set of points. Currently, we are getting 70% correct identifications with no false positives on over 200 samples tested. In addition to these results, there have been over fifty laboratory demonstrations done with no false positives on hundreds of non-matched prints. The VC allows for real-time input from the fingerprint scanner so matching is done at video rates and quick adjustments to compensate for rotation and large elastic distortions. More improvements to rotation and elastic distortions should be possible with improved composite filters.

The JTC has been very popular for fingerprint identification experiments and we plan to build a JTC to compare performance with the VC. The JTC has a lower resolution input but can be easier to maintain and use then the VC. Other NIST work [9] shows that fingerprint matching can be done at lower resolutions similar to those now capable in a JTC system. Previous JTC work [1-3,8] has produced results for fingerprint matching without using composite filters but filtering the MSF. In future work, we will test if composite filters can be used to improve JTC performance and make comparisons to previous JTC work.

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