First, the procedure goes into another image enhancing stage. Due to the fact of being critical for building the skeleton, an enhancement that attends to the local characteristics of the ridges is accomplished. This is done dividing the image into square blocks and applying directional filters to each block depending on the direction of fingerprint piece of ridge that fits into that block. The enhancement computes the directional fields for varying scales to be robust under noisy conditions. After the enhancement is done, a simple binarization is applied, followed by a skeletonizing procedure and elimination of spurious elements. Finally, the intersections of the skeleton with an imaginary line drawn between core and delta are counted. Figure 10 shows the result of the ridge counting process applied to a fingerprint.

![Figure 10: Ridge count process for fingerprint NIST-14 f0000041.wav. (a) line drawn between core and delta; (b) intersections found by the proposed method in the image skeleton.](image)

3 FBI classification formula and searching procedure

The FBI procedure for classifying a ten-fingerprint card consists of building a formula according to the results of fingerprint classification and sub-classification. This formula has the following components:

1. **Primary classification**: number corresponding to the position of whorls in the card.

2. **Secondary classification 1**: class of the index fingers (arch, tented arch, radial loop, ulnar loop, whorl).

3. **Secondary classification 2**: fingers with arch, tented arch or radial loop class.

4. **Sub-secondary classification**: fingerprint groups according to the ridge count of loops (and to the ridge tracing of whorls). Since in our tests we only considered loop sub-classification, the whorl case is not described. Loops appearing in the index, middle or ring fingers are grouped into 1 and 0, which corresponds to small and large ridge count respectively. The boundary for the group division depends on the finger considered.
5. **Major division:** when loops appear in thumbs, they are grouped into S, M, L (small, medium and large), according to the ridge count.

6. **Final:** ridge count of the right little finger. If this fingerprint is not a loop, the left little finger is considered. If this one still is not a loop, a whorl may be considered.

7. **Key:** ridge count of the first loop.

There are also extensions to the formula previously described, which are not explained here.

When searching for a match for fingerprints within any group classification, only prints that have a final (or key) within 2-ridge count on each side of the final (or key) are considered. For other ridge counts involved in the formula, when one more or one less count changes the designation of the loop between I and O (or S and M in extended sub-secondary), both groups must be searched.

4 **Results**

At present, there are *de facto* standard databases used to test fingerprint algorithms, namely NIST 4, 9 and 14.\textsuperscript{15-17} For the current study, a subset of NIST-14 was selected. NIST-14 consists of 2700 pairs of 10-fingerprint cards, totaling 54000 fingerprints. The pair of cards are known as the F-roll (the file card) and the S-roll (cards given to the FBI for search).

NIST-14 was constructed through a random selection of cards from the FBI files, thus mimicking the class natural distribution. Fingerprints were scanned at 512 dpi, with a size of 832 x 768, compressed using Wavelet Scalar Quantization, and saved with IHEAD file format.\textsuperscript{17} NIST-14 was selected for testing because it includes the classification/sub-classification assigned to the fingerprints by the FBI experts.

The fingerprints are classified according to NCIC\textsuperscript{b} classes.\textsuperscript{1} For the case of loops, the ridge count is included (01-49 for ulnar loop ridge count and 51-99 for radial loop ridge count).

Fingerprints sometimes present ambiguous patterns, due to e.g. a scar occurring in the fingerprint, low quality of the print rolling, or to ridge structures having the characteristics of two different classes. In these cases, it is not possible to assign a sole class to a fingerprint. Forensic experts also assign an alternative class to it. This is known as class referencing.

The ridge count of the proposed method applied to the database was compared with the FBI ridge count, giving an idea of how similar our method is compared to the forensic expert procedures.

On the other hand, the method was tested itself comparing F-roll ridge-count with S-roll ridge-count, giving an idea on the consistency of the method. For both tests, the ridge count difference was measured.

4.1 **NIST-14 Analysis**

NIST14 is grouped into directories containing 2000 fingerprints each (1000 prints - 2 rolls). The first directory of the database (mfcp2.1) was used as the test set, from which only the non-referenced loops were selected. The final set had 443 F-rolls and 512 S-rolls. Similar differences appear when analyzing the whole database.\textsuperscript{17} The ridge counts of the F and S rolls were compared and the result is depicted in Fig. 11.

As mentioned previously, every group of fingerprints within a ridge-count of two should be searched for a match according to the FBI procedure.\textsuperscript{1} The differences that appear in the database

\textsuperscript{b}National Crime Information Center