

ORIGINAL ARTICLE

## Ridgecounter: A program for obtaining semi-automated finger ridge counts

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### Abstract

Finger ridge count is a valuable quantitative phenotype used in a wide range of biological and anthropological research. However, the scoring of the phenotype is both labour intensive and error prone. This paper describes a freely available software program, RIDGECOUNTER, that can be used to obtain ridge counts from digitized prints (either collected using a digital fingerprint scanner or scanned from an inked print). The program yields semi-automated ridge counts and logs the location of the user-selected core and delta points to aid in the training of new researchers and ensure the repeatability of count. In a validity study of 451 prints, the semi-automated ridge counts of digital prints showed good agreement ( $r = 0.957$ ) with traditional manual counts of inked-rolled prints (which were obtained 2 years apart and counted by different researchers). In a reliability study of 200 prints, semi-automated ridge counts derived from digital prints collected at two different time points also showed good agreement ( $r = 0.962$ ) (the prints were obtained 2 years apart and counted by the same researcher). Although designed for use with fingerprints, the program is suitable for use with palm, foot or toe prints using user-defined landmarks.

**Keywords:** *Fingerprint, software, freeware*

### Introduction

The use of fingerprints in biometrics is well established and a number of highly sophisticated tools are available for forensic and security purposes. These tools generally rely on the location and formation of minutiae, capitalizing on the uniqueness of these features to

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distinguish between prints. Conversely, the use of dermatoglyphic variables in genetic, anthropological and medical research and practice concentrates on variation in pattern type and size. The principal quantitative dermatological measure used in these fields is the ridge count, a measure of pattern size obtained by counting the number of ridges that lie between the core (or centre of the pattern) and the triradii (or deltas). Ridge count has numerous attractive properties; it is immutable to the actual physical size of the finger, ridges or troughs and in the absence of traumatic injury remains constant across the lifespan, in addition when summed across all fingers the resultant total or absolute ridge count for most populations is normally distributed. Ridge counts are highly genetic in nature (genetic effects have been shown to account for 95–99% (Martin et al. 1982) of the variation in samples for individuals of European origin) and as such tend to be similar within familial and ethnic groups (Loesch 1983). As the properties which make ridge count a model trait in physical anthropology and human genetics reduce the application of this measure in forensic biometrics there has been relatively little biometric interest in these measures and ridge counts can not easily be obtained from commercially and freely available fingerprint analysis programs. Here we report the development of a freely available program, RIDGECOUNTER, designed to obtain ridge counts for non-forensic purposes from digital prints.

Traditionally, finger ridge count has been obtained by collecting rolled ink fingerprints on paper or card. The prints are then manually counted, usually with the assistance of a binocular dissecting microscope or a high-powered illuminated magnifying glass. For both the ulnar and radial sides of the print the core and triradii are identified, then the ridges falling between these landmarks are counted. While in theory this is a very straightforward task there are two main types of error that may lower the repeatability of measurements:

- (1) *Errors arising from print collection*, including incomplete rolling which results in omission of a triradius (this is particularly a problem with digits IV and V where obtaining a complete roll and maintaining even pressure are difficult), smudging, or omitting areas of the print due to changes in the pressure when rolling; over or under inking; and sweaty or dry skin.
- (2) *Errors arising during the counting process*, including incorrect identification of the central points within the core and triradii; the angle of the count between these points; counting vestigial ridges; omitting ‘underinked’ ridges; the use of a ‘guide’ line; and data entry error.

In addition, this task requires prolonged concentration, especially if large samples are analysed, which further increases the likelihood of errors. With the exception of permanently marking the rolled print there is no way to record the points and angle of count chosen, making it difficult to double check counts and complicating the training of new researchers.

More recent data collection methods exploit technological advances in biometrics and security systems and have led to the availability of relatively low cost electronic fingerprint scanners. Some scanners, such as those designed to enhance the security of laptop computers and data storage devices can only record ‘dab’ prints. However, a number of scanners that can record live rolled prints have also become available. These scanners are compact, light and highly portable, making them suitable for use with a laptop computer in field situations. The ‘livescan’ feature of these scanners allows the researcher to check the print as it is obtained to ensure all important features are clearly visible. In addition, the data collection is clean and does not stain the fingers, avoiding the negative connotations and stigma associated with forensic fingerprinting and potentially increasing study participation.

The collection of digital fingerprints (or high resolution scans of inked prints) allows for permanent non-degradable data storage and allows the possibility of automated or

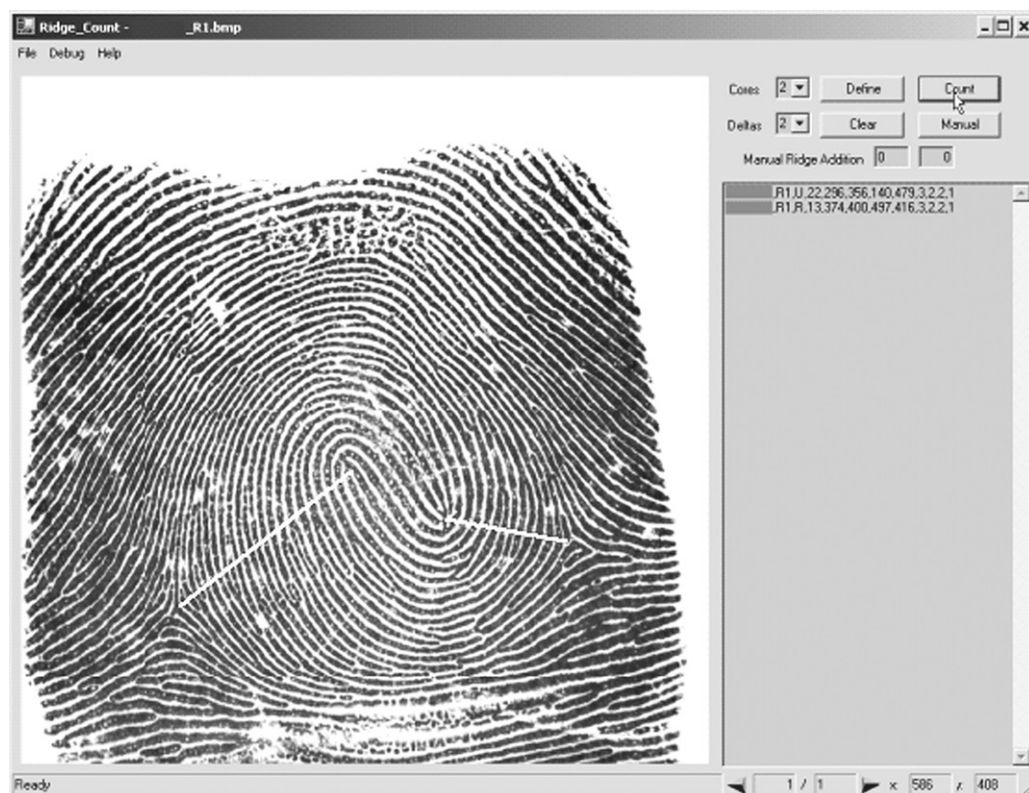


Figure 1. A screen shot of the RIDGECOUNTER program in use. The example print is a whorl with two cores and two deltas. The white lines indicate the points selected by the user and the angle of count taken across the print (note that thin red lines are actually used within the program). The ridge count results (and the points selected) are summarized in the result window, yielding ulnar and radial counts of 22 and 13 ridges, respectively.

semi-automated processing and ridge counting. While there are an abundance of programs designed to analyse fingerprint data for forensic and security purposes using minutiae types and count, the core-triradii ridge counts are not of forensic interest, and as such are not reported by these software. We designed the RIDGECOUNTER program specifically in an attempt to fill this gap. Although designed for use with fingerprints, RIDGECOUNTER could be used to obtain ridge counts from palm, toe or foot prints using user-defined landmarks (see Appendix 1). As shown in Figure 1 the digitized prints are opened and pre-processed within the program (either singularly or in a batch processing mode). The user then indicates, using the mouse, the number and location of the core(s) and triradial points (the coordinates of which are logged). The steps followed to calculate a ridge count are described below and summarized in the flow chart in Figure 2. File names are assumed to use an alphanumeric ID (of up to seven characters) followed by an underscore (\_), an R or L to denote which hand the print has been collected from, and a number to indicate which digit the print is from (i.e. 8001201\_R1 or case002\_L3). The results from all prints counted in a single session are saved to a .csv file when one exits the program using the Exit command in the File menu. The current date (day-month-year) is recorded within the file

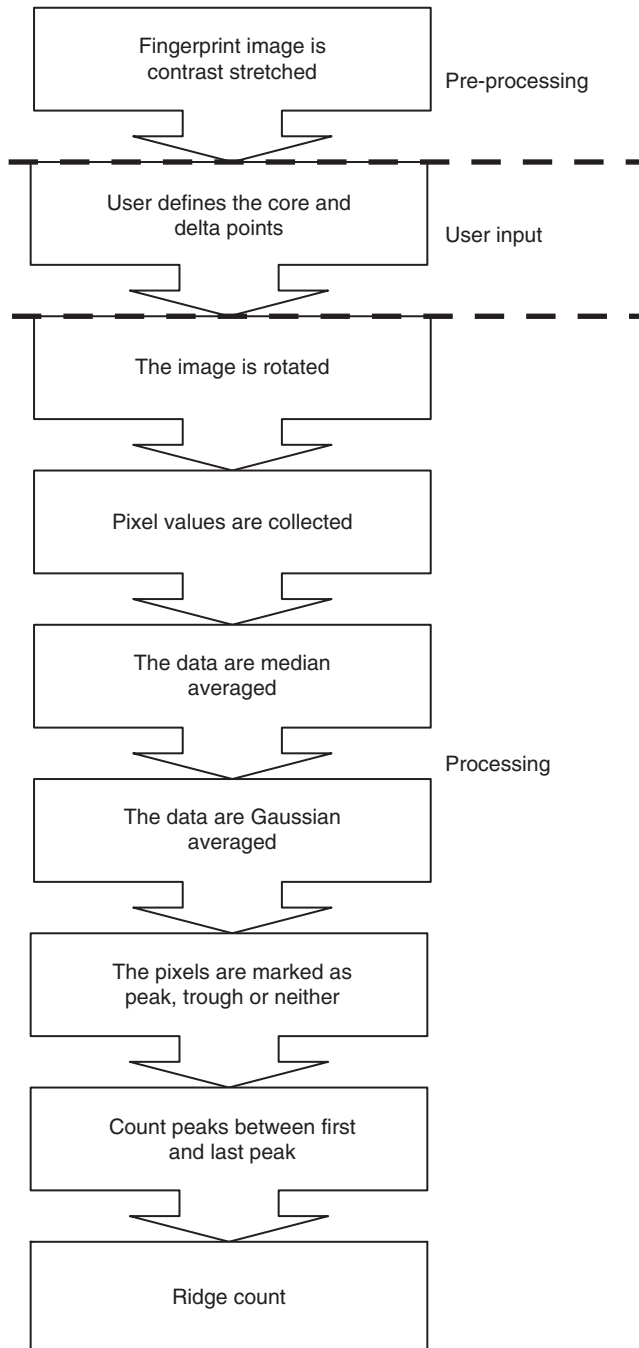


Figure 2. Flow chart showing the processes involved in obtaining ridge count.

name (i.e. count\_18-3-2007.csv). The file, which can be opened using Excel, contains the following variables (columns):

- ID (first seven characters of the file name, i.e. case002);
  - digit (the 9th and 10th characters of the filename, i.e. L3);
  - radial vs ulnar count;
  - count (with radial and ulnar counts reported on consecutive lines);
  - coordinates of the points selected;
  - four additional variables relating to Gaussian silhouette to ensure complete reproducibility of the count.
- (1) The image is loaded and pre-processed to enhance visibility of the ridges. The pre-processor processes the image before it is used, in this case displayed. Contrast stretching changes the range of pixels values to 0–255 – this is done using the following equation (Fisher et al. 2003)

$$P_{\text{out}} = (P_{\text{in}} - c) \left( \frac{b - a}{d - c} \right) + a$$

where, for a 8-bit greyscale image,  $P_{\text{out}}$  is the output grey level (0–255),  $P_{\text{in}}$  is the input grey level (0–255),  $a$  is the absolute minimum grey level (0),  $b$  is the absolute maximum grey level (255),  $c$  is the lowest grey level in the image, and  $d$  is the highest grey level in the image.

- (2) Using the drag down buttons the user then selects the number of core and delta points, and by clicking on the image, selects the core and delta points between which the count is to be made.
- (3) RIDGECOUNTER then undertakes the following steps in processing the image to prepare for ridge count calculation:
- The image is rotated (Figure 3).
  - The core and delta points are recalculated for the rotated image.
  - Pixels within a rectangle, defined by top left corner:  $x_{\text{core}} - 3, y_{\text{core}} - 3$ ; and bottom right corner:  $x_{\text{delta}} + 3, y_{\text{delta}} + 3$ , from the rotated image are stored.  $x_{\text{core}}$  and  $y_{\text{core}}$  are

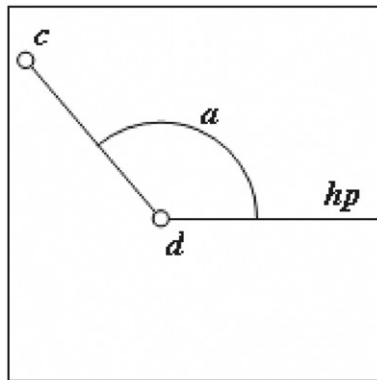


Figure 3. Image rotation by the angle between the core and delta point and horizontal plane, as shown below, where  $c$  is the core,  $d$  is the delta,  $hp$  is the horizontal plane, and  $a$  is the angle between  $c$ – $d$  and  $hp$ .

the recalculated  $x$  and  $y$  components of the core point, respectively, and  $x_{\text{delta}}$  and  $y_{\text{delta}}$  are the recalculated  $x$  and  $y$  components of the delta point, respectively.

(4) RIDGECOUNTER then performs the following steps in processing the data:

- The stored pixels (shown in Figure 4, A) are median averaged along in the  $y$  axis using an algorithm reported by Maio and Maltoni (1997). The results of this process are shown in Figure 4 (B).
- An approximated Gaussian silhouette is then applied along the  $x$  axis. The results of this process are shown in Figure 4 (C).
- Each of the processed pixels are classed as either a peak, trough or neither. A peak is defined as  $P_{x-1} < P_x > P_{x+1}$ , a trough is defined as  $P_{x-1} > P_x < P_{x+1}$ . This is illustrated in Figure 4 (D), which shows the cross-section of Figure 4 (C) with the peaks and troughs marked.
- The ridge count is then calculated as the number of the peaks between the first and last peak.
- The count is then classed as either an ulnar or radial count using Table I.

In developing RIDGECOUNTER we conducted a validity study in which we collected digital prints for a sample of 48 individuals who had previously had inked prints collected.

Table I. Principle used to determine whether a count is on the ulnar or radial side of the print.

		Delta is to the left or right of the core	
		Left	Right
Hand	Left	radial	ulnar
	Right	ulnar	radial

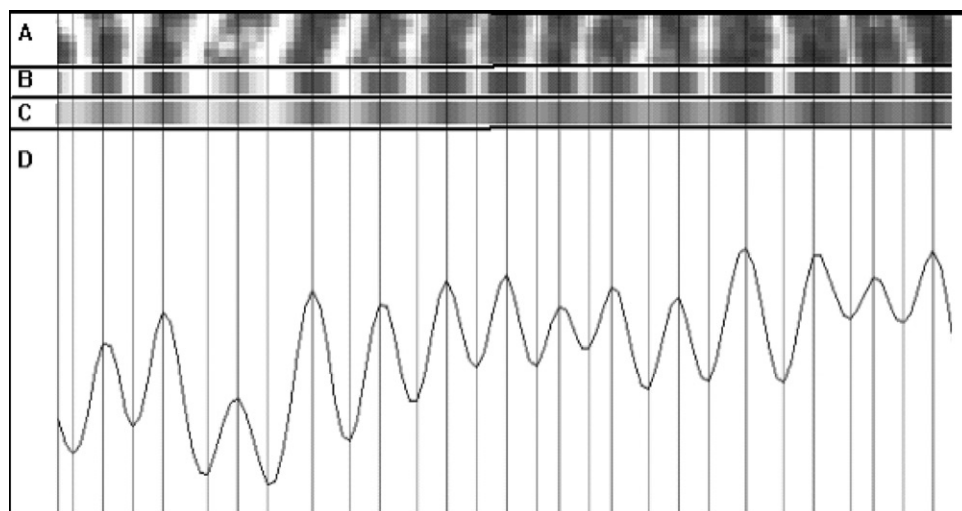


Figure 4. Stages involved in the processing of the data: A, raw data; B, median average of the raw data; C, Gaussian silhouetted version of the median averaged data; D, cross-section of Gaussian silhouetted data with the peaks and troughs marked.



In addition, we also examined the reliability of ridge counts derived from digital prints at two time points in a sample of 20 individuals. Given our intentions to use this program for research purposes in which accuracy is essential we wanted to study the program's performance on a range of real prints in which both the paper and digital prints varied in quality rather than an idealized image set. These validation and reliability studies are described below.

## Methods

### *Participants*

The prints used in this study were collected from Australian adolescent twins and their siblings as part of an ongoing investigation of the genetic and environmental influences on cognition and mole development (a risk factor for melanoma). The protocols of these studies have been described in detail elsewhere (Wright and Martin 2004). In summary, data are collected from these participants when they are 12, 14 and 16 years of age. Usually fingerprints are only collected from the participants at their first participation in the study. However, we took advantage of the longitudinal nature to perform two validation studies. The first study used data from 48 participants for whom manual counts were available from inked and semi-automated counts were available from digital prints that were collected 2 years later. The ridge counts obtained using these two methods were compared to assess the validity of the semi-automated ridge counts. The second study used the data from 20 participants for whom digital prints had been collected at two time points ( $t_1$  and  $t_2$ ) 2 years apart. The semi-automated ridge counts obtained from these two sets of prints were compared to assess the test-retest reliability.

### *Materials*

Rolled inked prints were collected using black fingerprinting ink on archival quality acid-free paper using traditional methods (Holt 1968; Loesch 1983). Ridge counts were then made from these prints using the counting rules outlined by Holt (1968) with the aid of a binocular dissecting microscope. Digital prints were collected using an optical scanner (Smiths Heimann Biometrics ACCO1394) which has a 30 mm × 30 mm live scan window and can be used to collect rolled prints. All prints were collected by research nurses with experience in collecting prints. Manual ridge counts were made by an expert (D.Z.L.) with over 20 years' experience. Semi-automated counts were made by two of the authors (D.A.P. and S.E.M.). Due to the nature of data collection, the digital and inked prints were collected 2–4 years apart.

### *Analyses*

In order to accurately gauge the performance of the RIDGECOUNTER program across a range of print qualities, the only inclusion criterion for the study were that both manual and semi-automated ridge counts must be available for the participants. Zero counts arising from arches and 'tented' loops were excluded in both studies. For the first study, there were 604 counts made from 451 prints from 48 participants that satisfied this criterion. Ulnar and radial counts were considered separately. Illegible inked prints led to the exclusion of

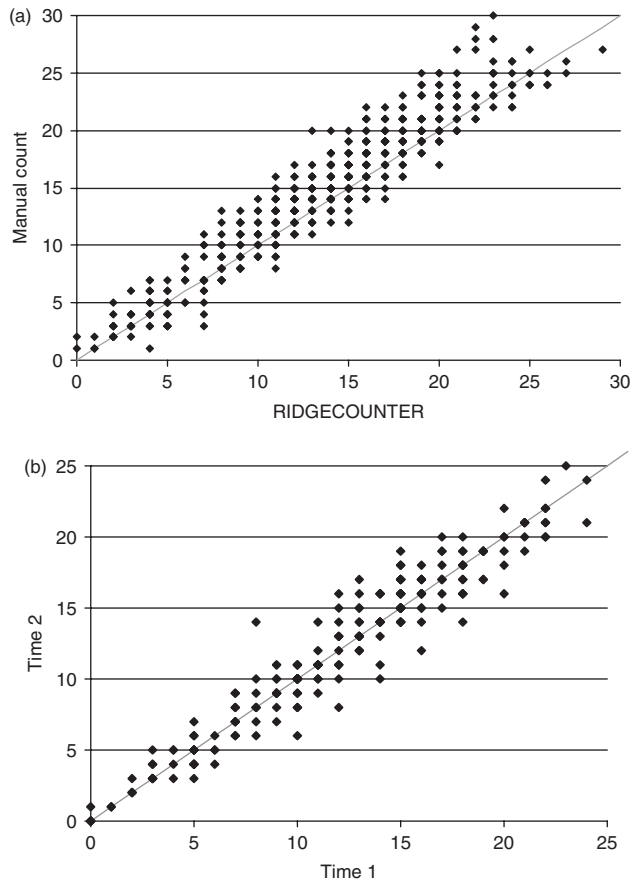


Figure 5. Scatter plot showing the correspondence between ridge counts from (a) manual and semi-automated (RIDGECOUNTER) methods for 604 counts from 451 prints from 48 individuals and (b) semi-automated (RIDGECOUNTER) methods from two sets of digital prints for 220 counts from 200 prints from 20 individuals. Reference lines ( $x=y$ ) are provided in grey.

39 prints from these participants. For the second study, there were 220 counts made from 200 prints from 20 participants that satisfied this criterion. Pearson correlations and linear regressions were used to examine the accuracy and reliability of semi-automated ridge counts.

## Results

### Study 1

As shown in Figure 5a, the manual counts taken from the inked prints and semi-automated counts taken from digital prints were highly correlated ( $r=0.957$ ). As expected, regression of the semi-automated counts (ac) on the manual counts (mc) yielded the revealed a significant beta coefficient ( $p<0.0001$ ;  $mc=1.028ac+0.582$ ). In addition, the intercept also differed from zero ( $p=0.001$ ), indicating that manual counts tended to be higher than



Table II. Discrepancies between manual and semi-automated ridge counts on 48 individuals (Study 1) and semi-automated counts on 20 individuals from digital prints collected 2 years apart (Study 2).

Discrepancy	Study 1			Study 2		
	Frequency	%	Cumulative %	Frequency	%	Cumulative %
0	142	23.51	23.5	89	40.45	40.5
1	218	36.09	59.6	69	31.36	71.8
2	122	20.20	79.8	44	20.00	91.8
3	70	11.59	91.4	8	3.64	95.5
4	28	4.64	96.0	9	4.09	99.5
5	16	2.65	98.7	–	–	99.5
6	5	0.83	99.5	1	0.45	100.0
7	3	0.50	100.0	–	–	100.0

the semi-automated counts by 0.582 of a single ridge. As shown in Table II, of the 604 counts 142 yielded the same manual and semi-automated counts while in 340 counts the discrepancies were two or fewer ridges. The larger discrepancies between the counts were predominantly due to poor quality of the inked prints (as shown in Figure 6) and reliability in the selection of the core and delta locations for more complex patterns.

### Study 2

Semi-automated counts made from two sets of digital prints collected 2 years apart were highly correlated,  $r=0.962$  (Figure 5b). Regression of the counts from prints collected at time 1 ( $t_1$ ) on the counts from prints collected at time 2 ( $t_2$ ) yielded a significant beta coefficient ( $p<0.0001$ ;  $t_1=0.971t_2+0.441$ ) but the intercept did not differ from zero ( $p=0.08$ ). As shown in Table II, of the 220 counts 89 yielded the same manual and semi-automated counts, while in an additional 113 counts the discrepancies were two or fewer ridges. Only 18 counts yielded a larger discrepancy, and of these counts four were due to a single individual.

### Computational efficiency

The main computational limitation encountered using the program was associated with the image pre-processor, which took 3.35 s per image, on an 800 MHz Intel Celeron. Computation of the actual ridge count was fast; with counting taking  $<0.4$  s on a 800 MHz Intel Celeron, and  $<0.1$  s on an 4000+ AMD Athlon 64. Comparative timings of the pre-processor and ridge counts are given in Tables III and IV. In our experience, a skilled user can process around 200 prints per hour.

### Discussion

The results of our reliability studies showed that RIDGECOUNTER could be used to provide accurate semi-automated ridge counts from digitized print images. These results are particularly promising as these prints were not an idealized test set, but rather real data sets

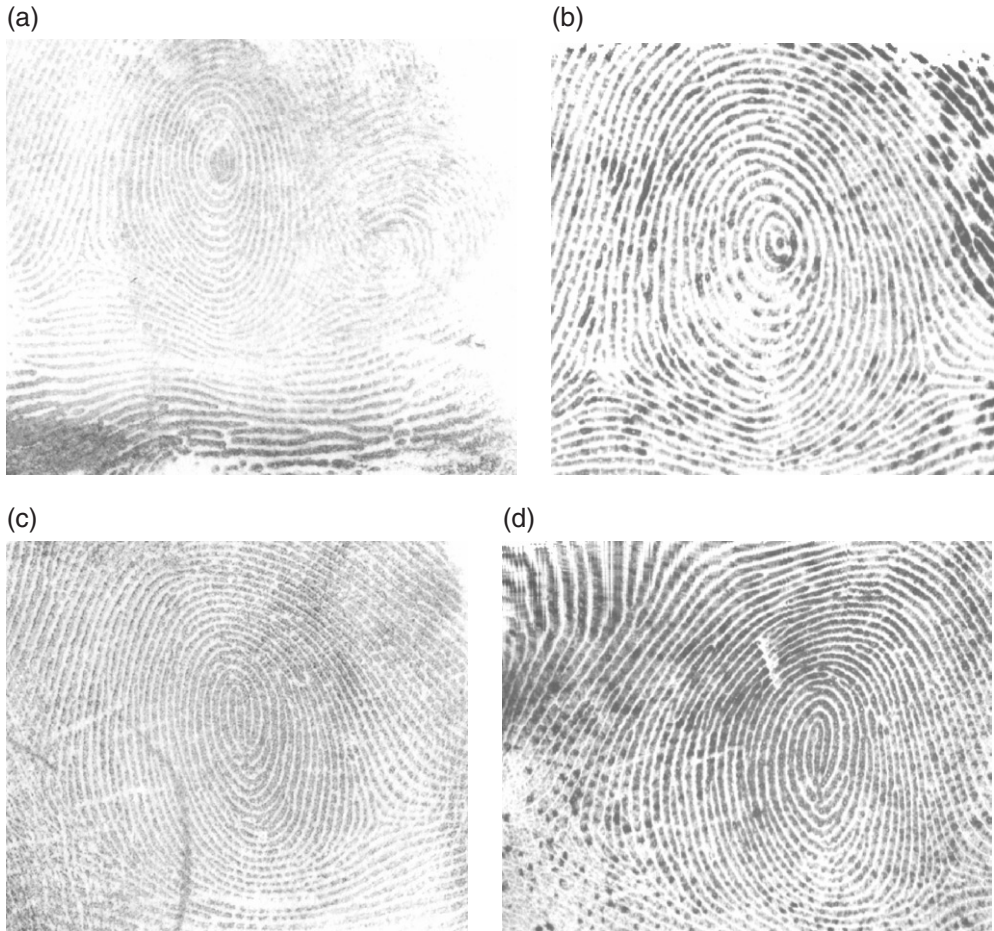


Figure 6. Examples of prints in which large discrepancies were observed between inked and digital prints. The right digit IV inked print in (a) yielded manual ulnar and radial counts of 19 and 20, while the digital print in (b) yielded semi-automated counts of 16 and 13. An examination of the inked print reveals a secondary print underlying the primary print, while the digital print shows some areas requiring interpolation due to inconsistent pressure while rolling; in this case it is likely that a combination of these factors explain these discrepancies. Conversely, when considering left digit II shown in (c) and (d) it is clear that the discrepancy arises from the interpolation of the inked print (c) yielding ulnar and radial counts of 17 and 30, while the digital print in (d) yielded semi-automated counts of 16 and 23. Note: Pencil marks indicating interpolation are visible in (c) while some edge distortion is present in the upper corner of (d).

Table III. Times taken (seconds) on various processors for the pre-processor.

	Intel Celeron 800 MHz	Intel Pentium 4 3.2 GHz	AMD Athlon XP 2000+	AMD Athlon 64 4000+
Mean	3.35	1.32	1.17	0.73
Median	3.35	1.31	1.17	0.73

Table IV. Times taken (seconds) on various processors for the ridge count to be computed excluding the pre-processor.

	Intel Celeron 800 MHz	Intel Pentium 4 3.2 GHz	AMD Athlon XP 2000+	AMD Athlon 64 4000+
Mean	0.37	0.12	0.13	0.07
Median	0.37	0.13	0.13	0.06

in which manual and digitized prints of the same person were collected at least 2 years apart and counted by different researchers. The correlations between counts taken from different prints here are similar to those reported by Bracha et al. (1992), who report an inter-rater correlation (the same set of prints were counted by two researchers) of total ridge count of 0.98 for 46 individuals. Similarly, Mustanski et al. (2002) report an inter-rater correlation of total ridge count of 0.92 for 100 individuals.

There are a number of possible sources of error which may explain the observed discrepancies. While ridge count *per se* does not change over time, the quality of prints obtained from the same individual at two time points can differ markedly. Differences in skin condition, roll pressure and humidity can produce artefacts which reduce the repeatability of measures. Data entry of the manual counts is another possible source of error, requiring the researcher to correctly record the ulnar and radial counts of each finger. While the RIDGECOUNTER program logs the coordinates of the core and delta making the counts completely reproducible this is not possible using the manual count method, so we were unable to compare the points selected and the angle of count that were used to make manual and semi-automated counts. In our experience, a skilled user can process around 200 prints per hour. We have found this process to be more efficient than the manual counting process in which counting, data entry and data checking are usually undertaken as separate stages in which operator fatigue and inattention can cause error. Using our procedures and software, prints are collected, stored and processed in a fixed order, minimizing the risk of data entry error, not least since radial and ulnar counts are always correctly assigned (Table I).

As expected, the performance of RIDGECOUNTER is sensitive to the quality of the digital image and manual counting may be superior for under-inked or faded images. Thus, by allowing for manual interpolation through the addition or subtraction of ridges while examining the magnified digital image, RIDGECOUNTER combines the best qualities of both automated and manual counting. It is envisioned that future improvements to this program will concentrate on the processing of poor quality images. After selection of the core and delta, Gaussian averaging is applied to the processed images. While this avoids counting large sweat pores located within a ridge as dual ridges, this may also result in two very fine ridges that are close together being counted as a single ridge, particularly with low quality images. To this end we have avoided fully automating the software (although this is possible) and have built in 'interpolation' and 'flagging' functions which maybe used to add or subtract ridges from the count to correct for missing print areas, or compile a list of difficult prints requiring second opinions.

In summary, we have designed and implemented an accurate and easy to use ridge counting software package that is suitable for obtaining ridge counts from large numbers of fingerprint images for non-forensic purposes. The RIDGECOUNTER software is freely available from <http://vipbg.vcu.edu/~sarahme/ridgecount.html>.

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## Appendix 1. An example of computing non-digital dermatoglyphes with RIDGECOUNTER

As the program is semi-automated it is easy to compute non-digital ridge counts between triradi that do not involve cores. Here we show the steps involved in computing the subdigital  $a-b-c-d$  ridge counts from an inked palm print that has been scanned and saved as a JPEG file (see Figure A1).

- (1) First the print is opened using the **File > Open** command.

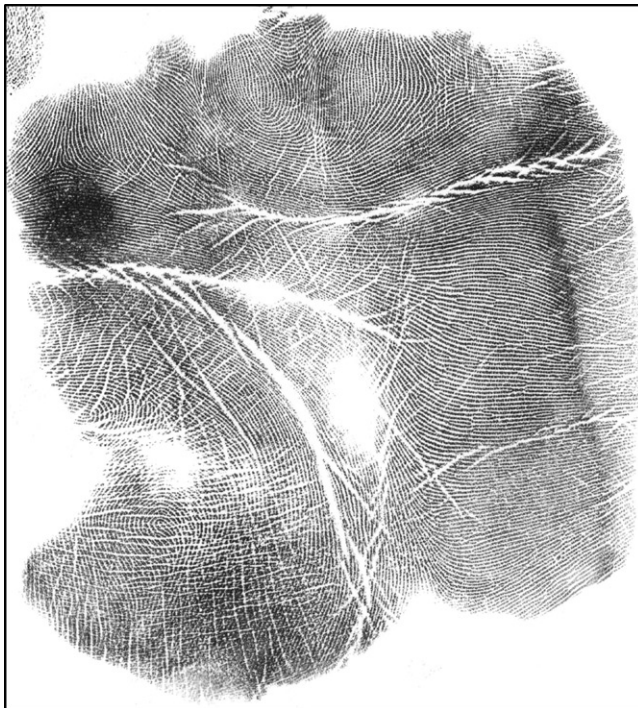


Figure A1. The left palm print used to demonstrate  $a-b-c-d$  counts.



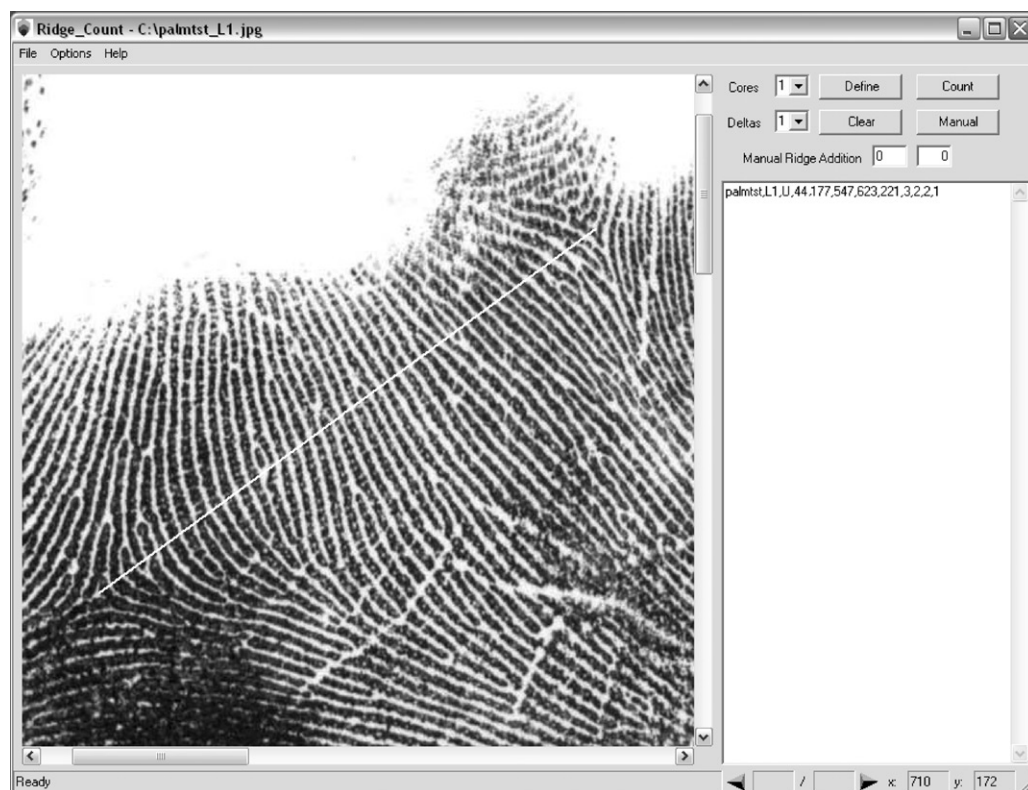


Figure A2. Using the RIDGECOUNTER program to obtain an  $a-b-c-d$  count. The white lines indicate the points selected by the user and the angle of count taken across the print (note that thin red lines are actually used within the program). The ridge count results (and the points selected) are summarized in the result window, yielding an  $a-b$  count of 44.

- (2) We would then move across the image (using the scroll bars) until both triradi were in view, then chose one core and one triradi using the drag-down menus on the right side of the screen and clicked on the **define** button.
- (3) Using the mouse we would then select (click on) the  $b$  triradi (which is acting as a pseudo core point). Following this we would select the  $a$  triradi, and click on the **count** button. This yields the  $a-b$  count as shown in Figure A2.
- (4) The  $b-c$  and  $c-d$  counts were calculated by repeating steps 2 and 3, choosing the relevant triradi in each case.

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