Document Title: Contactless Fingerprint Minutia Marking Report (Version 1.0)

Author(s): Lars Ericson, Ph.D., Aischa Prudhomme, Stephen Shine

Document No.: 249554

Date Received: December 2015

Award Number: 2010-IJ-CX-K024

Contactless Fingerprint Minutia Marking Report

(Version 1.0)

December 5, 2014

DOJ Office of Justice Programs
National Institute of Justice
Sensor, Surveillance, and Biometric Technologies (SSBT)
Center of Excellence (CoE)

Prepared for

Defense Biometrics & Forensics
OSD AT&L, ASD(R&E)

Prepared by

ManTech International Corporation®

ManTech Advanced Systems International
1000 Technology Drive, Suite 3310
Fairmont, West Virginia 26554
Telephone: (304) 368-4120
Fax: (304) 366-8096

Dr. Lars Ericson, Director

Aischa Prudhomme (CrossResolve, LLC)

Stephen Shine (Azimuth, Inc.)

UNCLASSIFIED

This project was supported by Award No. 2010-IJ-CX-K024 and 2014-ZD-CX-K001, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

In 2012, the National Institute of Justice (NIJ) Sensor, Surveillance, and Biometric Technologies (SSBT) Center of Excellence (CoE) undertook a biometric collection of fingerprint data from traditional scanners and next generation contactless devices – Contactless Fingerprint Collection, Round 1 (CFPv1). This data was the first of its kind across the two classes of scanners using the same subject population. The data was used to evaluate the match performance and interoperability of contactless versus contact fingerprint data. These results were published in a 2014 report – *Evaluation of Contact versus Contactless Fingerprint Data*.[1] However, this previous work did not explore the more detailed aspects of the captured fingerprints, such as the minutia markings and the effect of deformation on fingerprint biometric matching.

To build upon that work and expand the options available to researchers, the CoE has taken a subset of the CFPv1 data and had it vetted by a Certified Latent Print Examiner (CLPE) to correct minutia classifications and to delete incorrect and false minutiae. The result is a companion dataset of Electronic Biometric Specification Transmission (EBTS) files with vetted minutia markings and fingerprint images that can be used for more detailed and robust contactless fingerprint analyses in future work.

1.1 About the SSBT CoE

The NIJ SSBT CoE is a center within the National Law Enforcement and Corrections Technology Center (NLECTC) System.[2] The Center provides scientific and technical support to NIJ's research and development (R&D) efforts. The Center also provides technology assistance, information, and support to criminal justice agencies. The Center supports the sensor and surveillance portfolio and biometrics portfolio. The CoEs are the authoritative resource within the NLECTC System for both practitioners and developers in their technology area(s) of focus. The primary role of the CoEs is to assist in the transition of law enforcement technology from the laboratory into practice by first adopters.

NOTE: Fingerprint images contained in this report are reproduced with permission from the collected subjects for research reporting purposes in accordance with Institutional Review Board (IRB) approved protocols.

2.0 DATA

2.1 Data Source: WVU Fingerprint Collection

Data processing was performed on a subset of data from a fingerprint dataset collected by West Virginia University (WVU). For WVU IRB and data request purposes, the collection, protocol, and dataset are formally titled "ManTech Innovations Fingerprint Study." The dataset is available for use by third-party research organizations by submitting an email request to wvubiometricdata@mail.wvu.edu. The full report detailing the WVU fingerprint collection is publically available.[3] Fingerprint data was collected from 500 unique subjects in a controlled, sterile environment during the time period of April – July 2012 on the following devices:

- Rolled-ink fingerprint cards – Digitized at 500 pixels per inch (ppi) and 1000 ppi
- Legacy Fingerprint Devices:
    a. Cross Match Guardian R2 – Rolled and plain fingers
    b. i3 DigID Mini – Rolled and plain fingers
    c. L1 TouchPrint 5300 – Rolled and plain fingers
    d. SEEK II – Rolled and plain fingers
- Contactless Fingerprint Devices
    a. Touchless Biometric Systems (TBS) 3D Enroll Device – Individual fingers
    b. FlashScan 3D Single Finger D1 Scanner – Individual fingers
    c. FlashScan 3D 4-Finger Slap D4 Scanner – Plain fingers
        i. *Due to technical issues, the D4 was not operational during the entire collection. As a result, data from only 184 subjects was collected on the FS3D D4.*

2.2 Data Selection: Right Index Finger

For the follow-on effort, data processing (and future analysis) was limited to the Right Index fingerprints rolled (or rolled-equivalent) collected from ~500 subjects using four devices. This was chosen due to resource and schedule limitations. The device subsets were selected to facilitate baseline and comparative analyses of traditional and contactless systems. Data processed and discussed in this report is from the following devices:

1. Cross Match Guardian R2 (CMR2)
2. SEEK II
3. TBS 3D Enroll (HT1 output)
4. FlashScan 3D D1

2.3 Data Output: Companion Dataset

The result of this effort is a companion dataset to the WVU primary fingerprint dataset called – "Innovations Fingerprint Study Minutia Dataset." The dataset contains Latent Friction Ridge Features Search (LFFS) Electronic Biometrics Transmission Specification (EBTS) files and the collected grayscale image files. Original and CLPE processed versions of the files, as well as the

corresponding original image files, are contained in the dataset for testing and comparison purposes. The EBTS files have the following features:

- Conformance to ANSI/NIST-ITL 1-2011.
- Type-9 minutia records encoded in the FBI Extended Feature Set (EFS) Profile 2: Quick Minutia Search standard with data in Field Block 9.300-9.399.
- Type-13 latent image record, in accordance to ANSI/NIST-ITL 1-2011.
- Fingerprint image possessing 500 ppi resolution in field 13.999.
- Minutiae markings produced by the Neurotechnology Megamatcher 4.5 feature extractor.

The companion set can be requested for release to third parties following the same procedures as the parent set (see Section 2.1 Data Source: WVU Fingerprint Collection).

2.4 Data Preparation

Prior to being handed over to the CLPE for vetting and processing, the fingerprint data underwent several preparation steps. As mentioned previously the originating dataset was the WVU Innovations Fingerprint Study, also known as the Contactless Fingerprint dataset (CFPv1). Due to schedule and resource limitations, only the right index finger images were selected. This finger was chosen because it is one of the most common fingers presented during a verification or identification encounter when only one finger is required. Similarly, only four device image subsets were selected due to resource constraints. The CMR2 was used as the baseline traditional gallery in the previous contactless fingerprint (CFP) analyses. The SEEK II was chosen as a traditional platen scanner to be used in comparison to the CFP devices. It was selected over the other traditional devices in the CFPv1 dataset because 1) Being a mobile device there is likely to be the greatest deviations from the Guardian, and 2) Operationally, subjects are enrolled with a livescan but queried when encountered in the field with a mobile device. Finally the two CFP data sets were selected (i.e., TBS 3D Enroll and FlashScan 3D D1 Single-Finger Scanner) to meet the primary objectives.

Once the raw image data was identified, all four subsets of images were reviewed to correct any file naming errors to ensure that subject IDs were properly represented. In addition any duplicate subject IDs were removed (in CFPv1 each subject was collected twice with each device). This review removed one (1) duplicate and renamed two (2) files.

The next preparation step was to use the MegaMatcher (MM) minutia extractor to produce EBTS files with minutiae. Custom software was created to allow all the images to be submitted as inputs to the extractor, which then identified and marked minutiae in an automated manner. The Custom software then output an EBTS file with Type 9 converting the MM markers to the EFS Quick Search Profile 2 (QSP2) Specification, Type 13 storing the input image, and added reference information in Type 1 and Type 2 records. This conversion was necessary to allow the EBTS files to be read in to the Federal Bureau of Investigation (FBI) Universal Latent Workstation (ULW) software tool, which would be used by the CLPE to review and correct minutia markings. The differences between the MM and EFS QSP2 minutia marking conventions are highlighted in Table 1.

Table 1: MM vs. EFS Minutia Conventions

Attribute	MM Features[4]	EFS Features[5]
Origin	Top Left of Region of Interest	Top Left of Region of Interest
X Position	Units of ppi	Units of 10 micrometers
Y Position	Units of ppi	Units of 10 micrometers
Angle	Units of π/128; Counterclockwise from the right horizontal axis	Units of degrees; Counterclockwise from the right horizontal axis
Type	Line end (E), Bifurcation (B), or Unknown (U)	Ridge ending (E), Bifurcation (B), or Unknown (U)

In addition to the Type 9 records, certain other EBTS fields were filled to either designate dataset information or to avoid misunderstandings by future users. Required fields that are standard for EBTS files are not covered here. For explanations of other fields, readers should reference ANSI/NIST ITL[5] or FBI EBTS 9.3[6]. Dataset specific fields are described in Table 2. In addition, an example for an original and a markup EBTS files are provided in Sections

2.6 Example LFFS File: Original and 2.7 Example LFFS File: Markup.

Table 2: Minutia Dataset EBTS Field Descriptions

Field#	Field Descriptor	Dataset Entry	Notes
1.07	Destination Agency Identifier	NOONEABIS	Data is not to be submitted to any criminal justice agency
1.08	Originating Agency Identifier	NIJTEST3D	Data originates from NIJ project
1.09	Transaction Control Number	Original: <Filename> Markup: <Number>	For markup files, the number is not meaningful
2.006	Attention Indicator	Original: ATTN: NIJ TEST DATA Markup: <Filename>	Data originates from NIJ project
2.010	Contributor Case Identifier Number	Prefix: <subject ID> Identifier: <collection date>	Required for LFFS format
2.011	Contributor Case Identifier Extension	<finger position>	Required for LFFS format
9.901	Annotations	Markup: <Actions taken in ULW>	Actions taken by CLPE in ULW during processing or original file
13.003	Impression Type	1 {Live-scan rolled}	Same entry for all devices, including CFP
13.004	Source Agency/ORI	NIJTEST3D	Data originates from NIJ project
13.005	Latent Capture Date	<Date>	Date of LFFS creation, not CFPv1 collection
13.020	Comment	<Original Filename>	Same original filename for both sets
13.200	User-Defined Field	<Device>	Device image was collected with

2.5 Post-Processing Data Preparations

Upon receipt of the CLPE-processed EBTS files (see Section 3.0 MINUTIA PROCESSING APPROACH), the dataset underwent two more preparation steps to make them completely ready for use by researchers in biometrics matching run experiments.

The first additional step involved correcting the markup LFFS files to be made re-compliant with EFS requirements for EBTS files containing No Cores and/or No Deltas.[7] After utilizing ULW version 6.4.1, it was discovered that the output LFFS EFS QPS2 files do not add a Field 9.325 or 9.326 when an original EBTS file with cores or deltas had those features deleted. In our situation, the vast majority of cores and deltas marked by automated extraction by MM were determined to be incorrectly placed and therefore deleted. EFS requires that if no cores or deltas are present that fields are added to the EBTS file explicitly designating that case. In an effort to make the resulting companion dataset EFS compliant and more friendly to future users, a batch utility was created to take in all the markup files and add in Fields 9.325 and 9.326 as needed.

Finally, the device datasets were cross referenced to remove any subject files that did not exist in all four sets to guarantee 100% N:N compatibility in future matching run analyses. All of these steps resulted in a final dataset of **471 each of original image files, original LFFS files, and LFFS markup files**.

2.6 Example LFFS File: Original

```
Data file: Z:\Original
Uniform\Rindexlffs\CMR2S1\1034056_07102012_1_2_bmp.lffs

Number of records:
  1 Type-1
  1 Type-2
  1 Type-9
  1 Type-13

Record 1: Transaction Information
  1.01                        Record Length      LEN    159
  1.02                              Version      VER    0400
  1.03                         File Content      CNT
     a                        Record Number           1 1
     b                                  IDC           1 3
     a                        Record Number           2 2
     b                                  IDC           2 00
     a                        Record Number           3 9
     b                                  IDC           3 01
     a                        Record Number           4 13
     b                                  IDC           4 01
  1.04                  Type of Transaction      TOT    LFFS
  1.05                                 Date      DAT    Jun 24,2014
  1.07                Destination Agency ID      DAI    NOONEABIS
  1.08                Originating Agency ID      ORI    NIJTEST3D
  1.09              Transaction Control Num      TCN
1034056_07102012_1_2_bmp-20140624
  1.11           Native Scanning Resolution      NSR    00.00
  1.12             Nominal Trans Resolution      NTR    00.00

Record 2: Descriptive Text
 2.001                        Record Length      LEN    93
 2.002                 Image/Rec Designator      IDC    00
 2.006                  Attention Indicator      ATN    ATTN: NIJ TEST DATA
 2.010           Contributor Case ID Number      CIN
     a                               Prefix           1 1034056
     b                           Identifier           1 07102012
 2.011       Contributor Case ID Extension      CIX    02
 2.076                             Priority      PRI    3 {Arson, drugs,
personal crimes, and property crimes}
 2.079      Number of Candidates Requested      NCR    19

Record 9: Fingerprint Feature Data
 9.001                        Record Length      LEN    2079
 9.002                 Image/Rec Designator      IDC    01
 9.003                      Impression Type      IMP    1 {Live-scan rolled}
 9.004                      Minutiae Format      FMT    U
 9.010                                           1 0
 9.011                                           1 1
 9.300                   Region of Interest      ROI
     a                                Width           1 4053
     b                               Height           1 3799
     c                   Horizontal Offset            1 0000
     d                     Vertical Offset            1 0000
     e                              Polygon           1 0,0-4053,0-4053,3799-
0,3799
 9.301                          Orientation      ORT
     a                            Direction           1 0
     b                          Uncertainty           1 15
 9.302              Finger/Palm Position(s)      FPP
     a                          Position Code         1 02
     b                        Finger segment          1
```

```
     c     Off-Center Fingerprint Position            1
     d                             Polygon            1
 9.303             EFS Feature Set Profile            1 2
 9.307              Pattern Classification      PAT
     a              General Classification            1 LS
     b                   Subclassification            1
     c                  Delta relationship            1
 9.320                               Cores      COR
     a                                   X            1 01829
     b                                   Y            1 01961
     c                           Direction            1 255
     d      Radius of Position Uncertainty            1 000
     e               Direction Uncertainty            1
 9.321                              Deltas      DEL
     a                                   X            1 01961
     b                                   Y            1 02398
     c                       Direction up             1 361
     d                     Direction left             1 361
     e                    Direction right             1 361
     f                               Type             1
     g      Radius of Position Uncertainty            1
     h            Direction Uncertainty up            1
     i          Direction Uncertainty left            1
     j         Direction Uncertainty right            1
 9.331                            Minutiae      MIN
     a                                   X            1 02428
     b                                   Y            1 01173
     c                               Theta            1 142
     d                                Type            1 E
     e      Radius of Position Uncertainty            1
     f               Direction Uncertainty            1
     a                                   X            2 02352
     b                                   Y            2 01189
     c                               Theta            2 306
     d                                Type            2 E
     e      Radius of Position Uncertainty            2
     f               Direction Uncertainty            2
[Remaining minutiae removed for space…]

Record 13: Latent Image
13.001               Logical Record Length      LEN  1 600209
13.002         Image Designation Character      IDC  1 01
13.003                     Impression Type      IMP  1 1 {Live-scan rolled}
13.004                  Source Agency/ORI       SRC  1 NIJTEST3D
13.005                Latent Capture Date       LCD  1 Jun 24,2014
13.006              Horizontal Line Length      HLL  1 800
13.007                Vertical Line Length      VLL  1 750
13.008                        Scale Units       SLC  1 1
13.009              Horizontal Pixel Scale      HPS  1 500
13.010                Vertical Pixel Scale      VPS  1 500
13.011               Compression Algorithm      CGA  1 NONE
13.012                      Bits Per Pixel      BPX  1 8
13.013                    Finger Position       FGP  1 2
13.020                             Comment      COM  1
1034056_07102012_1_2_bmp
13.200                                               1 CrossmatchR2
Right index
Live-scan rolled, Uncompressed image
Width: 800, Height: 750, Compression Rate: 1:1, Offset: 2539, Length: 600000,
IDC: 1
ANSI/NIST Image 1 MD5 hash:
```

2.7 Example LFFS File: Markup

```
Data     file:     Z:\Markup     Uniform     Fixed\Rindexlffs     Fixed\CMR2S1
Fixed\1034056_07102012_1_2_bmp_rev_fix.lffs

Number of records:
  1 Type-1
  1 Type-2
  1 Type-9
  1 Type-13

Record 1: Transaction Information
  1.01                        Record Length      LEN    226
  1.02                              Version      VER    0400
  1.03                         File Content      CNT
     a                        Record Number           1 1
     b                                  IDC           1 3
     a                        Record Number           2 2
     b                                  IDC           2 00
     a                        Record Number           3 9
     b                                  IDC           3 01
     a                        Record Number           4 13
     b                                  IDC           4 01
  1.04                  Type of Transaction      TOT    LFFS
  1.05                                 Date      DAT    Jun 24,2014
  1.06                Transaction Priority      PRY    2 {Routine}
  1.07               Destination Agency ID      DAI    NOONEABIS
  1.08               Originating Agency ID      ORI    NIJTEST3D
  1.09             Transaction Control Num      TCN    201411100949571050
  1.11           Native Scanning Resolution     NSR    19.69
  1.12             Nominal Trans Resolution     NTR    19.69
  1.13                          Domain Name      DOM
     a   Agency, Entity, or Implementation           1 NORAM
     b              Implementation Version           1 EBTS 9.4
  1.14                 Greenwich Mean Time      GMT    20140703043944Z
  1.15         Directory of Character Sets      DCS
     a                               Index           1 000
     b                                Name           1 ASCII
     c                             Version           1
  1.16   Application Profile Specification      APS
     a    Application Profile Organization           1 FBI
     b             Application Profile Name           1 EBTS
     c  Application Profile Version Number           1 9.4

Record 2: Descriptive Text
 2.001                        Record Length      LEN    154
 2.002                 Image/Rec Designator      IDC    00
 2.006                                    Attention  Indicator             ATN
!!1034056_07102012_1_2_bmp_rev
 2.010          Contributor Case ID Number      CIN
     a                               Prefix           1 1034056
     b                           Identifier           1 07102012
 2.011       Contributor Case ID Extension      CIX    02
 2.034        Pattern Level Classification      PAT
     a                         Finger Number           1 02
     b          Pattern Classification Code           1 LS {Left Slant Loop}
     c                           Reference 1           1
     d                           Reference 2           1
 2.074                      Finger Position      FGP  1 02 {Right index}
 2.076                                Priority       PRI     3 {Arson, drugs,
personal crimes, and property crimes}
 2.079      Number of Candidates Requested      NCR    19
 2.083         Add to Unsolved Latent File      ULF    N {No}
 2.095             Request Features Record      RFR    No
```

```
 2.098        Name of Designated Repository        NDR  1 1 {Criminal Master
File Records}
                                                       2 2 {Civil Records}

Record 9: Fingerprint Feature Data
 9.001                        Record Length      LEN    4116
 9.002                 Image/Rec Designator      IDC    01
 9.003                      Impression Type      IMP    1 {Live-scan rolled}
 9.004                      Minutiae Format      FMT    U
 9.010                                                  1 0
 9.011                                                  1 1
 9.300                   Region of Interest      ROI
     a                                Width             1 4054
     b                               Height             1 3800
     c                    Horizontal Offset             1 0000
     d                      Vertical Offset             1 0000
     e                              Polygon               1 0,0-4054,0-4054,3800-
0,3800
 9.301                          Orientation      ORT
     a                            Direction             1 0
     b                          Uncertainty             1 15
 9.302              Finger/Palm Position(s)      FPP
     a                         Position Code            1 02
     b                        Finger segment            1
     c     Off-Center Fingerprint Position              1
     d                              Polygon             1
 9.303              EFS Feature Set Profile             1 2
 9.307               Pattern Classification      PAT
     a               General Classification             1 LS
     b                    Subclassification             1
     c                   Delta relationship             1
 9.325                     No Cores Present               Y
 9.326                    No Deltas Present               Y
 9.331                             Minutiae      MIN
     a                                   X              1 02428
     b                                   Y              1 01173
     c                               Theta              1 142
     d                                Type              1 E
     e      Radius of Position Uncertainty              1 000
     f               Direction Uncertainty              1 000
     a                                   X              2 02352
     b                                   Y              2 01189
     c                               Theta              2 306
     d                                Type              2 E
     e      Radius of Position Uncertainty              2 000
     f               Direction Uncertainty              2 000
[Remaining minutiae removed for space…]

9.901                              Annotations      NOTE  1 7/3/2014 11:39:44 -
Opened ANSI/NIST File E:\Original\CMR2S1\1034056_07102012_1_2_bmp.lffs
                                                       2  7/3/2014  11:39:44  -
ANSI/NIST Image 1 MD5 hash: 407214CB 08D73036 1A8BAEF0 E5B3C40F
                                                       3  7/3/2014  12:01:12  -
AFIS Type: Extended Feature Set
                                                       4  7/3/2014  12:01:12  -
Pattern Class: Left Loop
                                                       5  7/3/2014  12:01:12  -
Orientation: 0 CCW ?15 degrees
                                                       6  7/3/2014  12:01:12  -
Tonal Reversal: No
                                                       7  7/3/2014  12:01:12  -
Minutiae:  100 (0 hidden due to min reliability threshold of 0%)
                                                       8  7/3/2014  12:01:12  -
Ridge Counts Manually Checked: Yes
```

```
                                                          9  7/3/2014  12:01:12  -
Skeletonized Image: No
                                                          10  7/3/2014  12:01:12  -
Saved     file     E:\MarkupCorrected\CMR2S1\1034056_07102012_1_2_bmp_rev.lffs
without errors using ULW 6.4.1
                                                          11  11/10/2014  09:31:40  -
Opened                                ANSI/NIST                                  File
F:\MarkupCorrected\CMR2S1\1034056_07102012_1_2_bmp_rev.lffs
                                                          12  11/10/2014  09:31:40  -
ANSI/NIST Image 1 MD5 hash: 407214CB 08D73036 1A8BAEF0 E5B3C40F
                                                          13  11/10/2014  09:50:15  -
AFIS Type: Extended Feature Set
                                                          14  11/10/2014  09:50:15  -
Pattern Class: Left Loop
                                                          15  11/10/2014  09:50:15  -
Orientation: 0 CCW ?15 degrees
                                                          16  11/10/2014  09:50:15  -
Tonal Reversal: No
                                                          17  11/10/2014  09:50:15  -
Minutiae:  99 (0 hidden due to min reliability threshold of 0%)
                                                          18  11/10/2014  09:50:15  -
Ridge Counts Manually Checked: Yes
                                                          19  11/10/2014  09:50:15  -
Skeletonized Image: No
                                                          20  11/10/2014  09:50:15  -
Saved     file     F:\MarkupCorrected\CMR2S1\1034056_07102012_1_2_bmp_rev.lffs
without errors using ULW 6.4.1

Record 13: Latent Image
13.001               Logical Record Length      LEN  1 600209
13.002         Image Designation Character      IDC  1 01
13.003                     Impression Type      IMP  1 1 {Live-scan rolled}
13.004                  Source Agency/ORI      SRC  1 NIJTEST3D
13.005                Latent Capture Date      LCD  1 Jun 24,2014
13.006              Horizontal Line Length      HLL  1 800
13.007                Vertical Line Length      VLL  1 750
13.008                          Scale Units      SLC  1 1
13.009              Horizontal Pixel Scale      HPS  1 500
13.010                Vertical Pixel Scale      VPS  1 500
13.011               Compression Algorithm      CGA  1 NONE
13.012                     Bits Per Pixel      BPX  1 8
13.013                    Finger Position      FGP  1 2
13.020                                          Comment          COM   1
1034056_07102012_1_2_bmp
13.200                                          1 CrossmatchR2
Right index
Live-scan rolled, Uncompressed image
Width: 800, Height: 750, Compression Rate: 1:1, Offset: 4704, Length: 600000,
IDC: 1
ANSI/NIST Image 1 MD5 hash: 407214CB 08D73036 1A8BAEF0 E5B3C40F
```

3.0 MINUTIA PROCESSING APPROACH

The images in each dataset were examined for the purpose of quality controlling the type and placement of minutiae markings using the analysis portion of the ACE-V methodology.[8,9] ACE-V is an acronym latent print examiners use to describe the methodology for analyzing, comparing, evaluating and verifying latent print impressions. Although the images from each of the datasets are technically scanned images of known fingerprint impressions and are not accidental in nature, the same methodology is also used for their examination.

When analyzing each print, three levels of friction ridge detail are considered, as well as the overall quality. At level 1, the examiner is looking at the direction of ridge flow, pattern formation and any other general morphological features. At level 2, the individual ridge paths and minutiae (e.g., bifurcations, ending ridges, and dots) are evaluated. The presence of scars, creases and incipient ridges are also evaluated. At level 3, other dimensional friction ridge attributes (e.g., width, edge shapes and pores) are examined and evaluated. Comprehensively, these three levels of friction ridge detail are taken into consideration when making a qualitative/quantitative determination of comparison suitability.

The pre-encoded LFFS images from each dataset were carefully analyzed then quality controlled for the correct type and proper placement of every minutia marking using the ULW software version 6.4.1. Other aspects which may affect the quality and quantity of the image, such as distortions resulting from contrast, tone, blurring, pixilation, incomplete capture, false creasing, rippling/waving, stretching, fragmentation and any other exaggeration of features, were also noted.

Specific ULW tools such as zoom, invert and tile vertical allow for the close up examination of each LFFS image. An image is simply acquired by either dragging the image from its folder location or opened directly from the interface using the “file” then “open EBTS file” tabs at the top of the task bar. Once the image is acquired it can then be examined and quality controlled for type and minutiae placement using the spacebar, mouse hover and right click program features. These features allow for the examination and deletion of any incorrect or false minutia markings. Minutiae with incorrect minutia types were changed to the correct type. Minutiae marked in an incorrect or false location, or with incorrect directional placement, were deleted. Note that no new minutia marks were added to the image, only the deletion of incorrect/false marks placed by the automated MM feature extractor. This approach was adopted due to schedule limitations, practical considerations regarding CLPE training (CLPEs are not trained to mark all minutiae on an image, but sufficient markings to facilitate a confident submission to an AFIS), and to maintain a focus on automated lights-out processing of fingerprint images by a matcher. As an aside, it was discovered during processing that if a minutia had the wrong type, then its location was likely incorrect. So effectively, (almost) all incorrect minutia types ended up being removed as well.

The ULW software only allows for two types of minutia encodings: bifurcations and ending ridges; for this reason, any other minutia encodings from features such as creases, scars, dots and incipient ridges are removed. To remove a minutia feature, the mouse pointer is hovered over the minutia until it turns yellow and then a right click will remove it. This process is repeated

until all incorrect and/or false minutiae are removed. Once the image has been quality controlled the modified LFFS image is then saved as a revised image into the "markup corrected" folder.

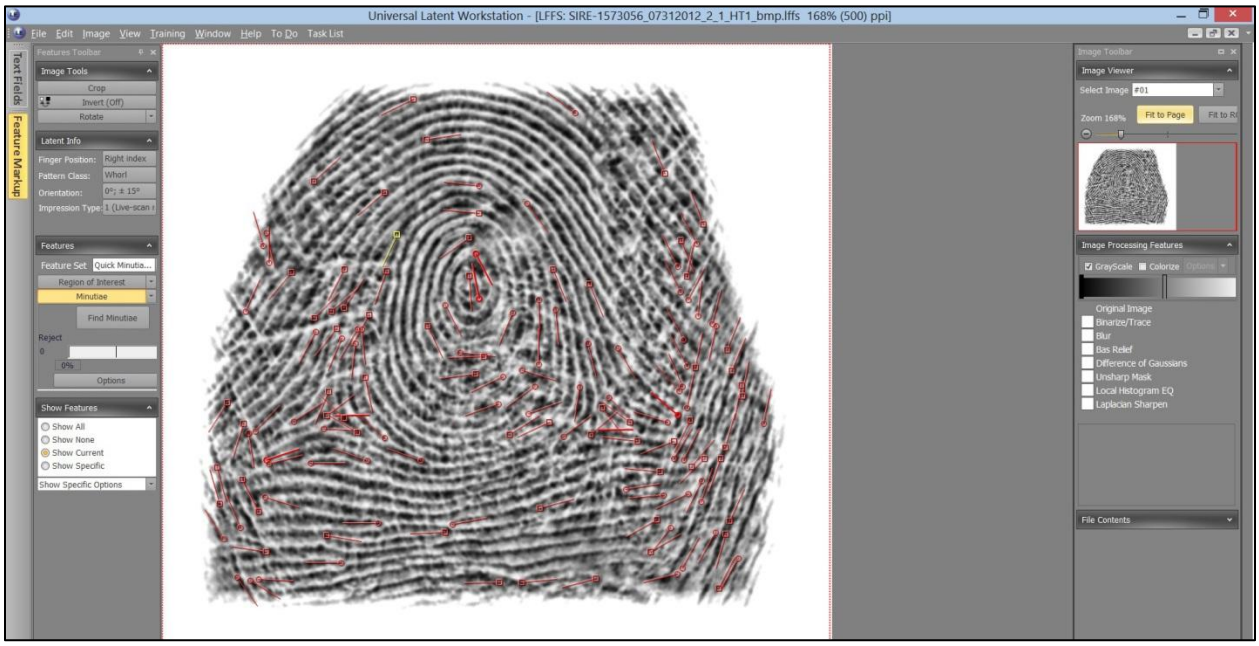

Figure 1: Viewing LFFS File in ULW

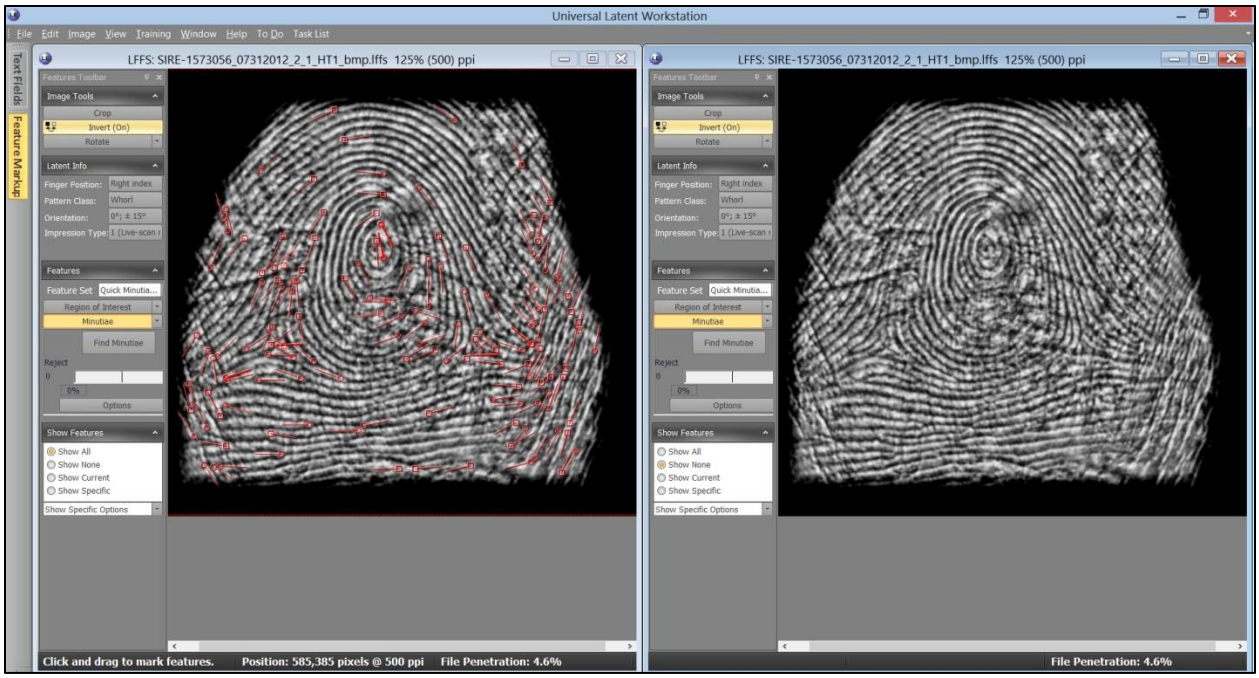

Figure 2: Comparison of Minutiae and Images in ULW
ULW interface displaying the same LFFS image with and without minutia encodings tiled vertical with the invert function.

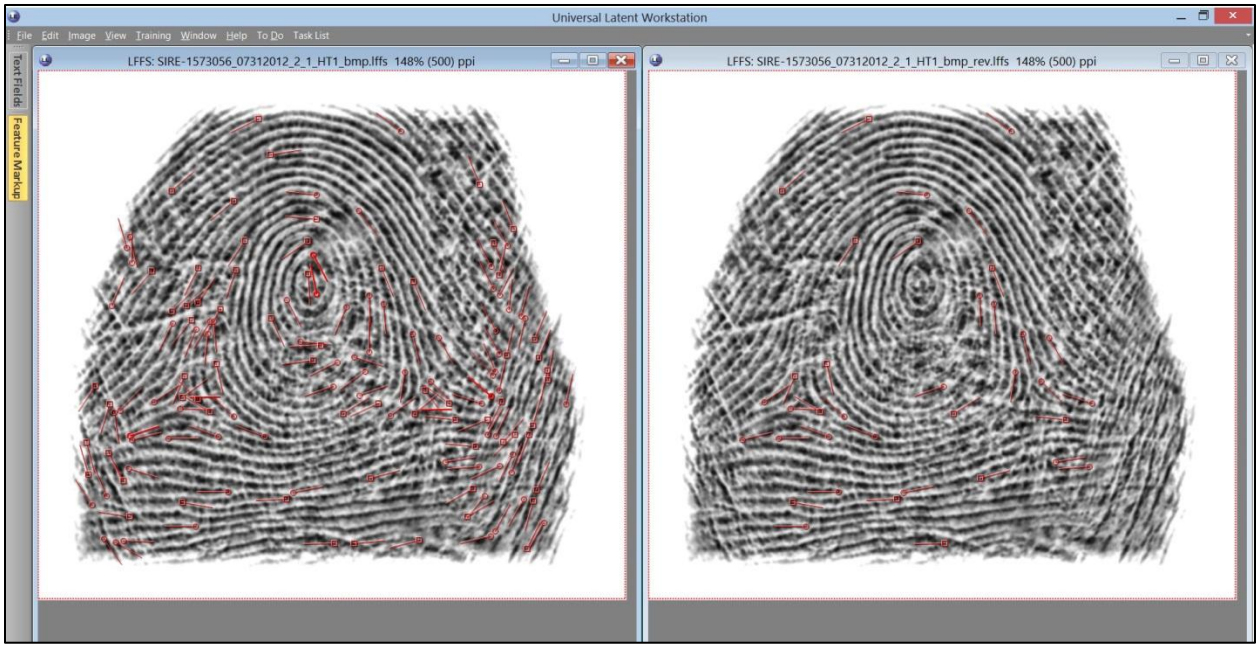

Figure 3: Minutiae Before & After Processing
The ULW interface displaying the same LFFS image before and after markup revision.

3.1 Minutia Processing Metrics

At the start of the LFFS image quality control portion of the project, metrics were collected to determine whether sufficient minutiae would be available after processing for use in comparative matching run analyses. The first twenty image files from each dataset were processed and tracked in detail. Minutia counts before and after processing were recorded for each file, as well as qualitative notes and comments observed by the CLPE during processing. Table 3 provides a summary of the minutia counts, with standard deviation errors. The percentage of original minutiae that survived the vetting process is also included. The number of remaining minutiae was determined acceptable for follow-on analyses. Specifically, sufficient minutiae remained such that if a notable portion is filtered out due to deviation or distortion criteria, there is a reasonable probability of over a dozen usable minutiae remaining.

Table 3: Minutia Processing Metrics

	Original Minutiae (OM)	OM StdDev	After Minutiae (AM)	AM StdDev	Remaining	Rem StdDev
CMR2	**107**	42	**60**	15	**62%**	20%
SEEK	**108**	33	**68**	15	**67%**	19%
FlashScan	**54**	21	**27**	8	**54%**	16%
TBS	**158**	39	**60**	16	**40%**	14%

4.0 CMR2 DATA SUBSET

4.1 Processing Metrics

As discussed in Section 3.1 Minutia Processing Metrics, the first 20 images of the CMR2 dataset were processed and the minutiae count before and after for each image recorded. There was an average of **107 ± 42** minutiae before and **60 ± 15** after processing (**62 ± 20%** survived).

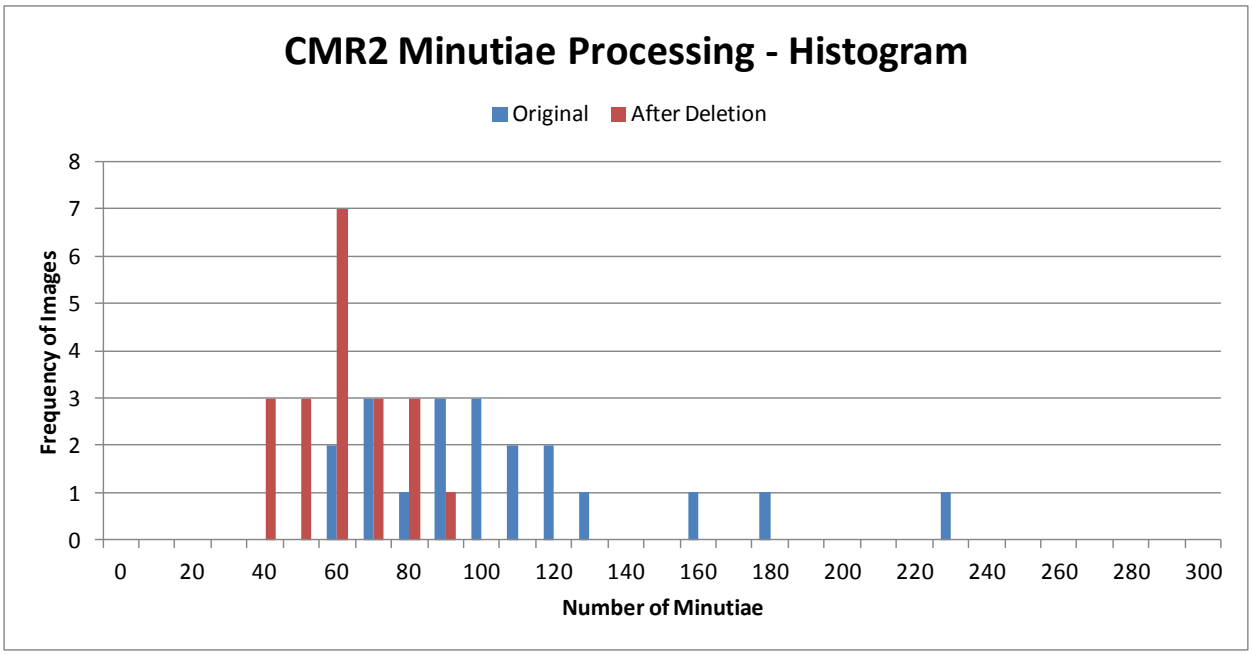

Figure 4: CMR2 Minutiae Metrics – Histogram

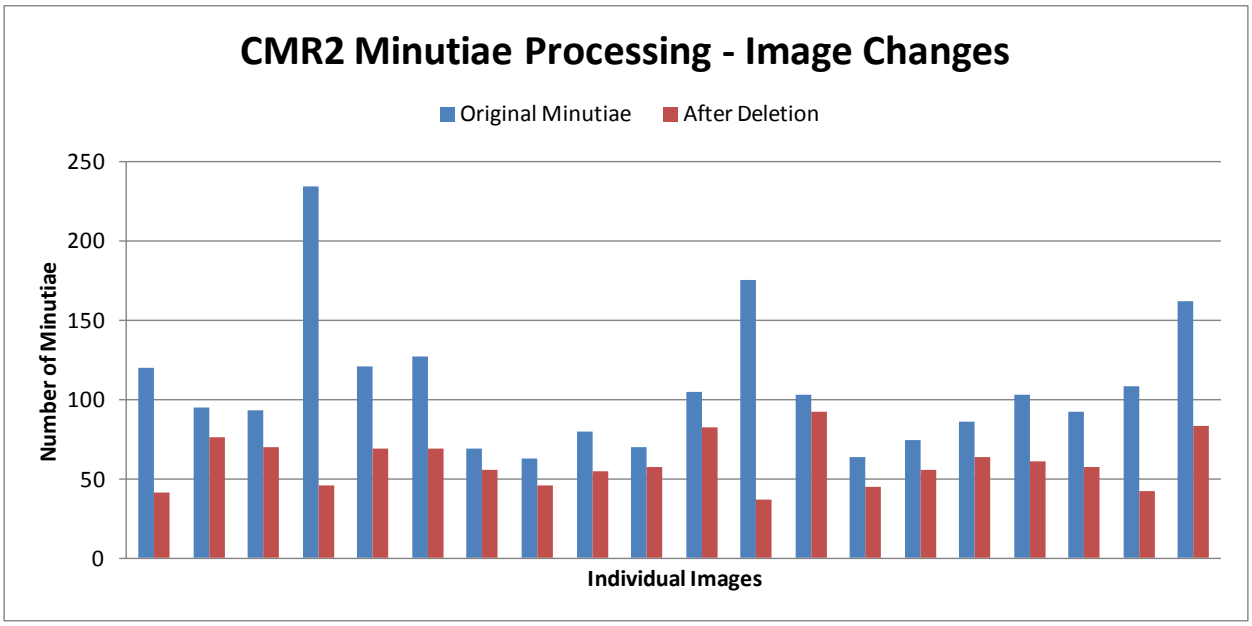

Figure 5: CMR2 Minutiae Metrics – Image Changes

4.2 Image Artifacts

4.2.1 Artifact: False Minutiae Creasing

Several images from the CMR2 set contained false minutiae as a result of prolific creasing. It is uncertain whether these creases were truly organic or a result of the scanning process; however, it must be noted that for most images with confirmed organic creases, false minutiae did not appear to be present.

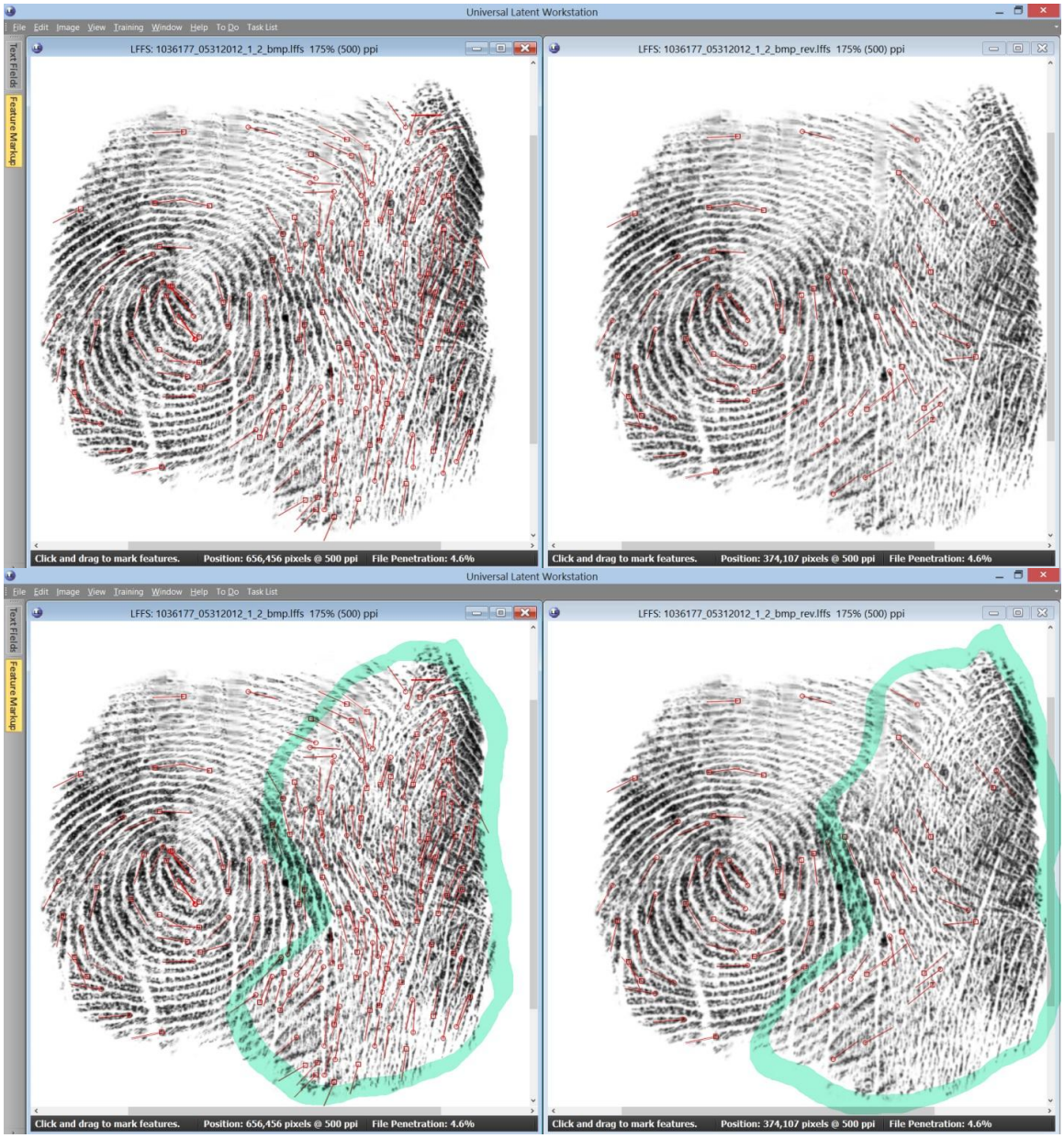

Figure 6: False Minutia Creasing (CMR2)
False minutiae in a heavily creased fingerprint before and after markup revision. Diagram of affected areas highlighted in green.

4.2.2 Artifact: Contrast Distortion

Several images from the CMR2 set displayed both heavy and light contrast issues, which were factors in the appearance of both false and/or incorrect minutiae placement.

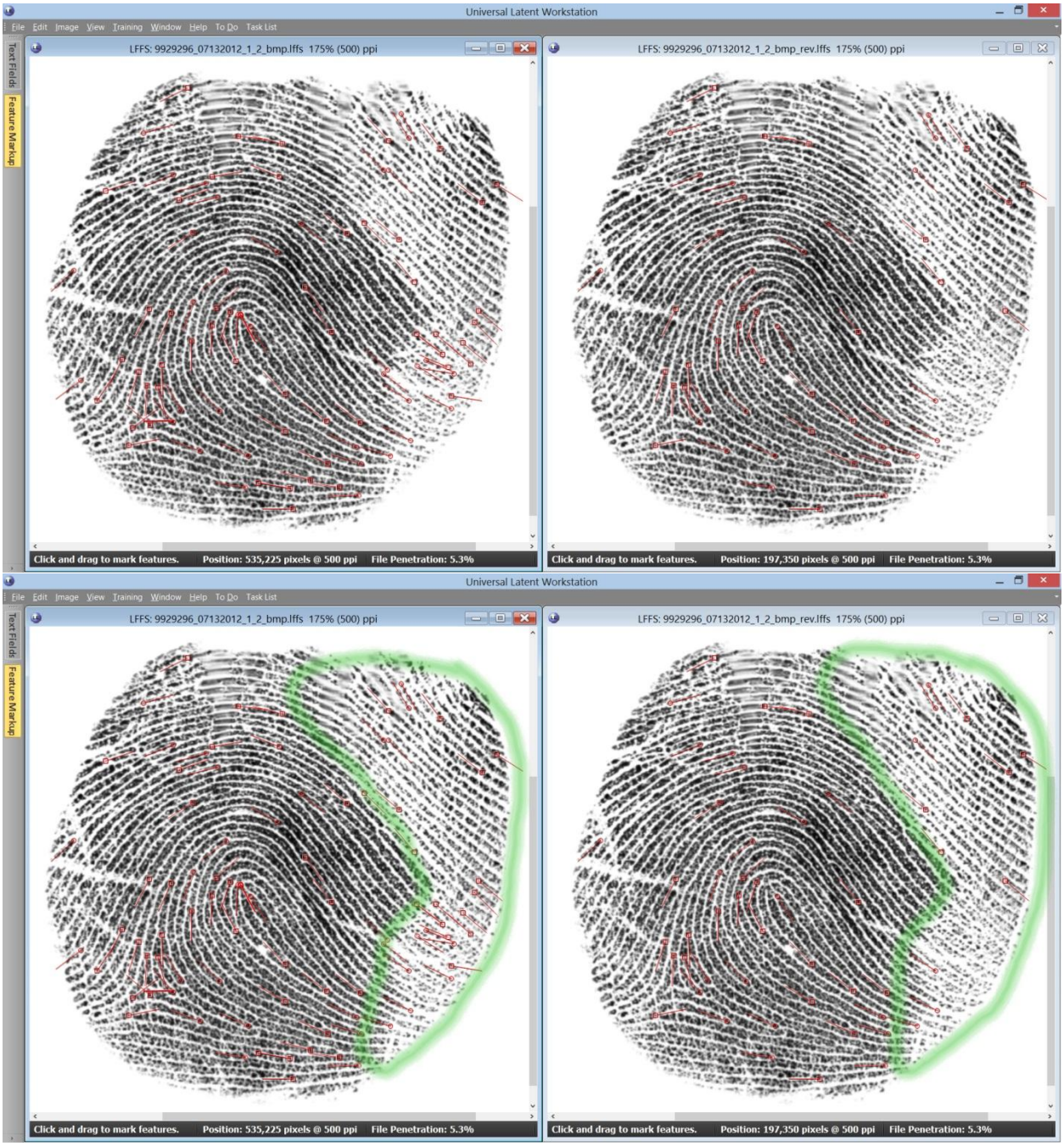

Figure 7: Contrast Distortion, Light (CMR2)
Light contrast distortion before and after markup revision. Diagram of affected area highlighted in green.

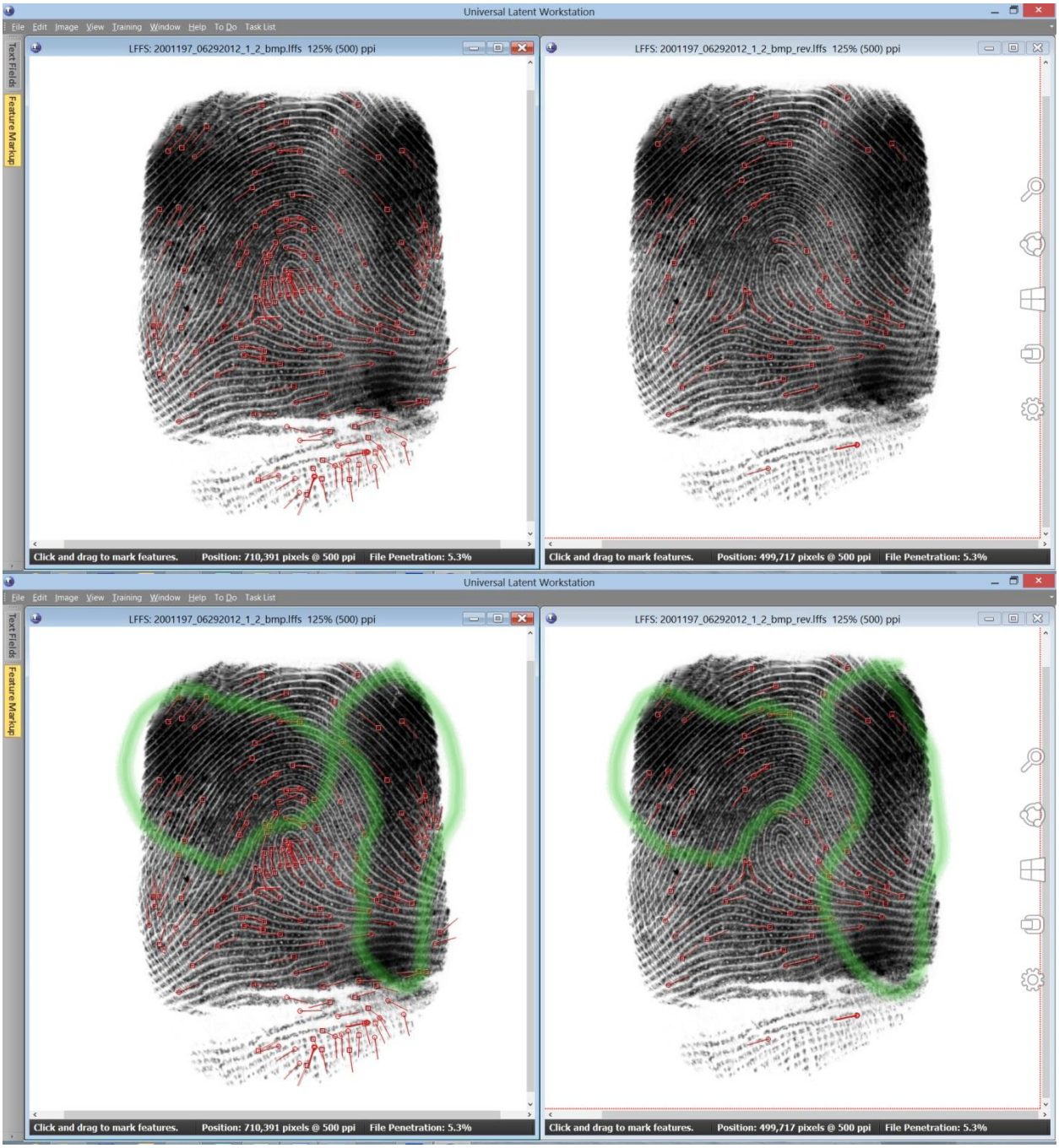

Figure 8: Contrast Distortion, Heavy (CMR2)
Heavy contrast distortion before and after markup revision. Diagram of affected area highlighted in green.

4.2.3 False/Incorrect Minutiae

Every single image in the CMR2 set was observed to have at least one or more incidents of false minutiae and/or incorrect minutiae type and/or incorrect minutiae placement.

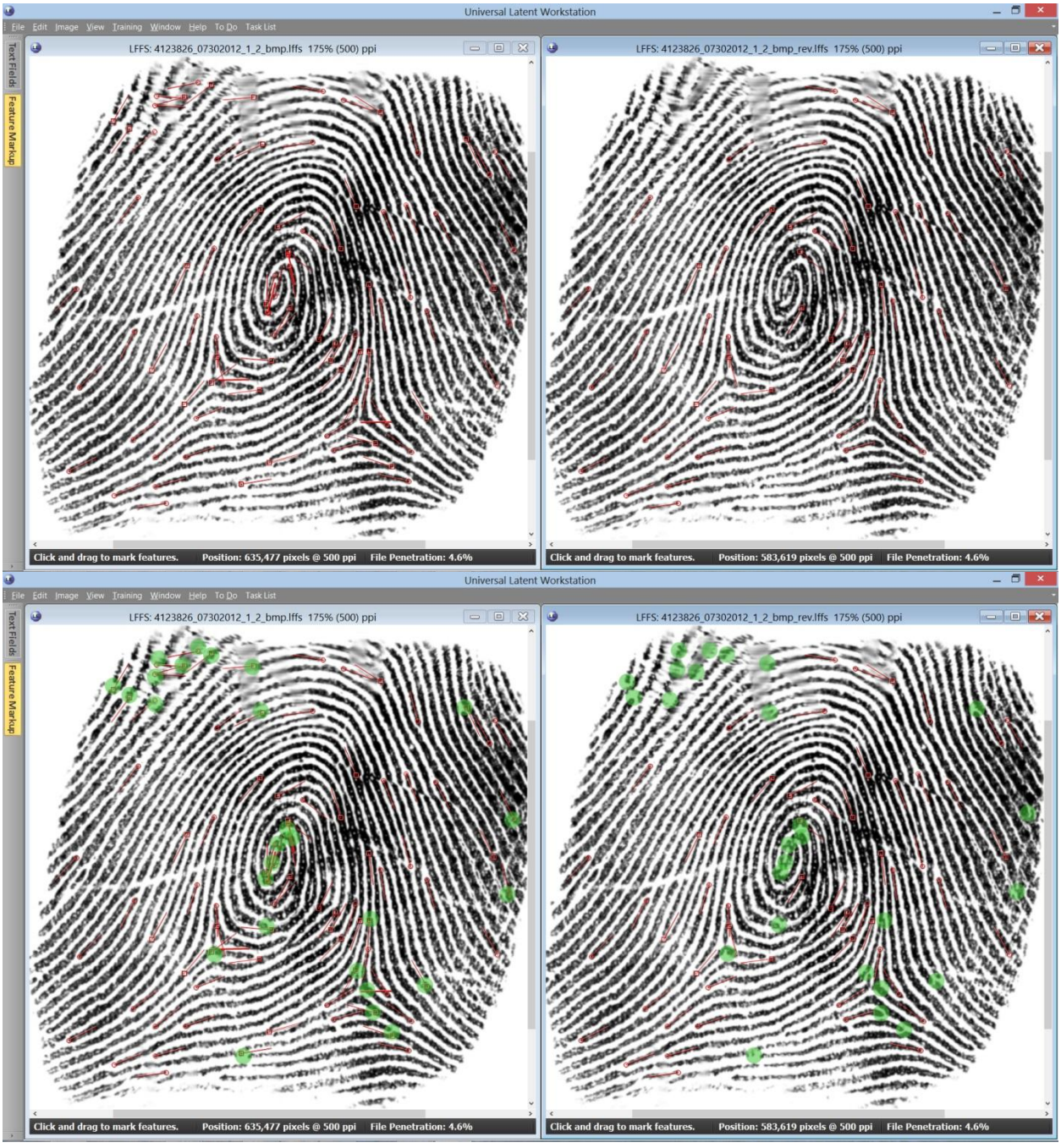

Figure 9: False Minutiae (CMR2)
False minutiae, incorrect minutiae type and incorrect minutiae placement before and after revision markup. Diagram of affected areas highlighted in green.

5.0 SEEK II DATA SUBSET

5.1 Processing Metrics

As discussed in Section 3.1 Minutia Processing Metrics, the first 20 images of the SEEK II dataset were processed and the minutiae count before and after for each image recorded. There was an average of **108 ± 33** minutiae before and **68 ± 15** after processing (**67 ± 19%** survived).

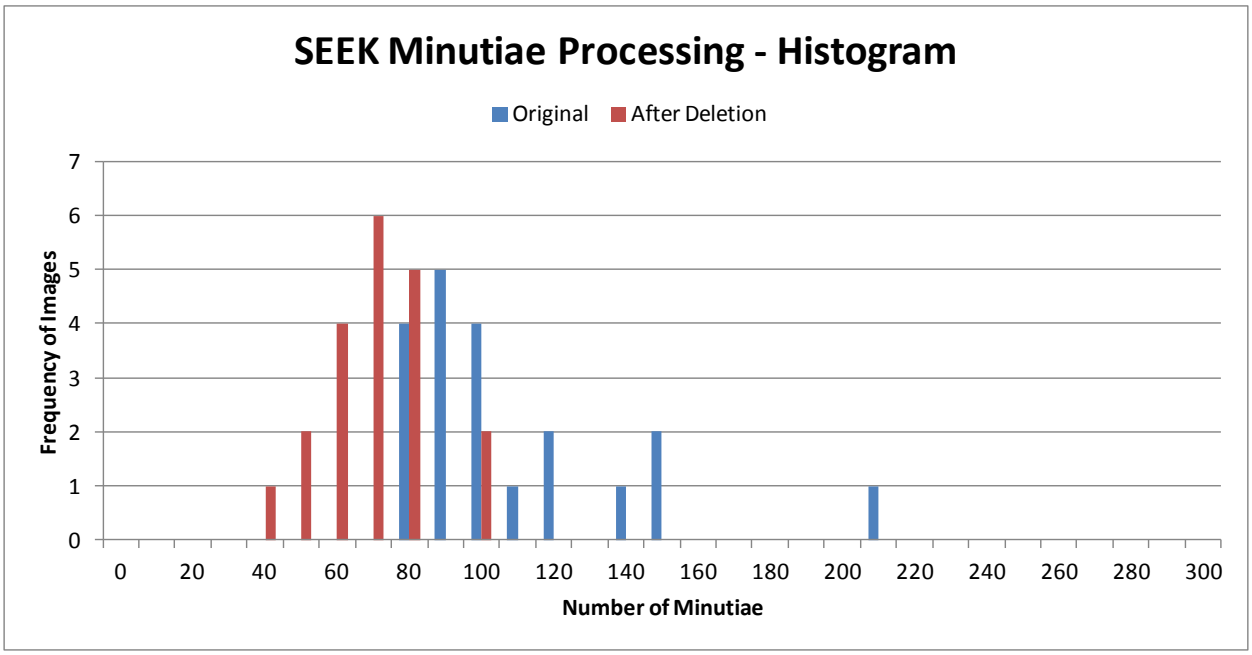

Figure 10: SEEK II Minutiae Metrics – Histogram

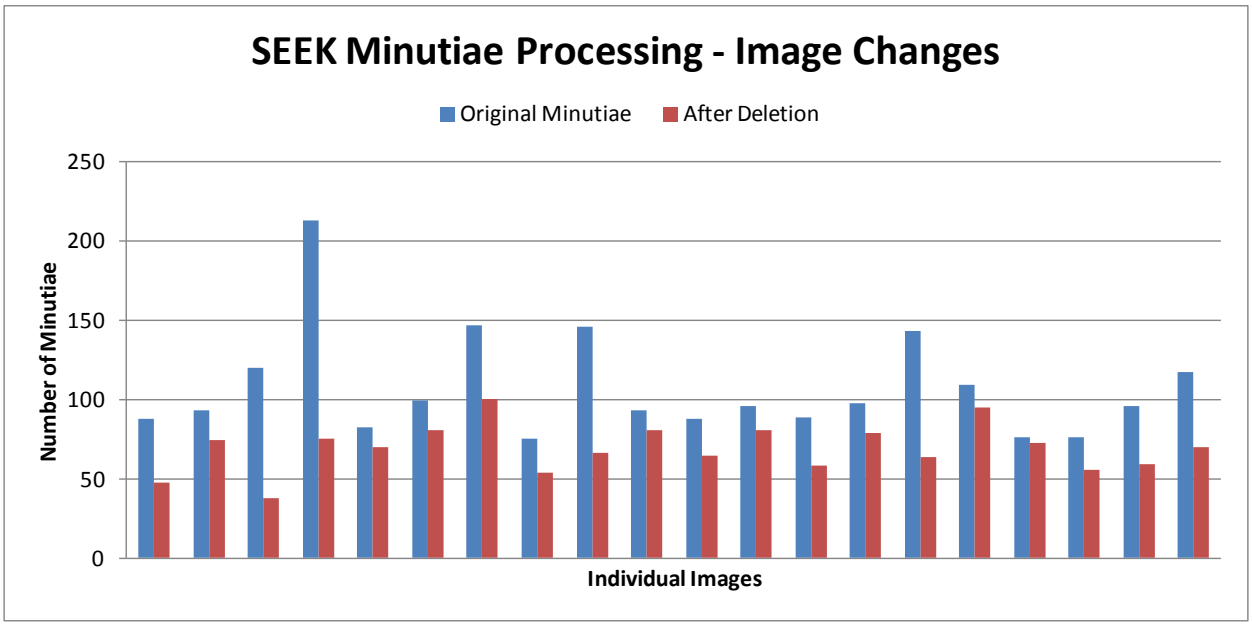

Figure 11: SEEK II Minutiae Metrics – Image Changes

5.2 Image Artifacts

5.2.1 False Minutiae Creasing

Several images from the SEEK dataset contained false minutiae as a result of prolific creasing. It is uncertain whether these creases were organic or from the scanning process. It must be noted that false minutiae did not appear to be present in most of the images with organic creases.

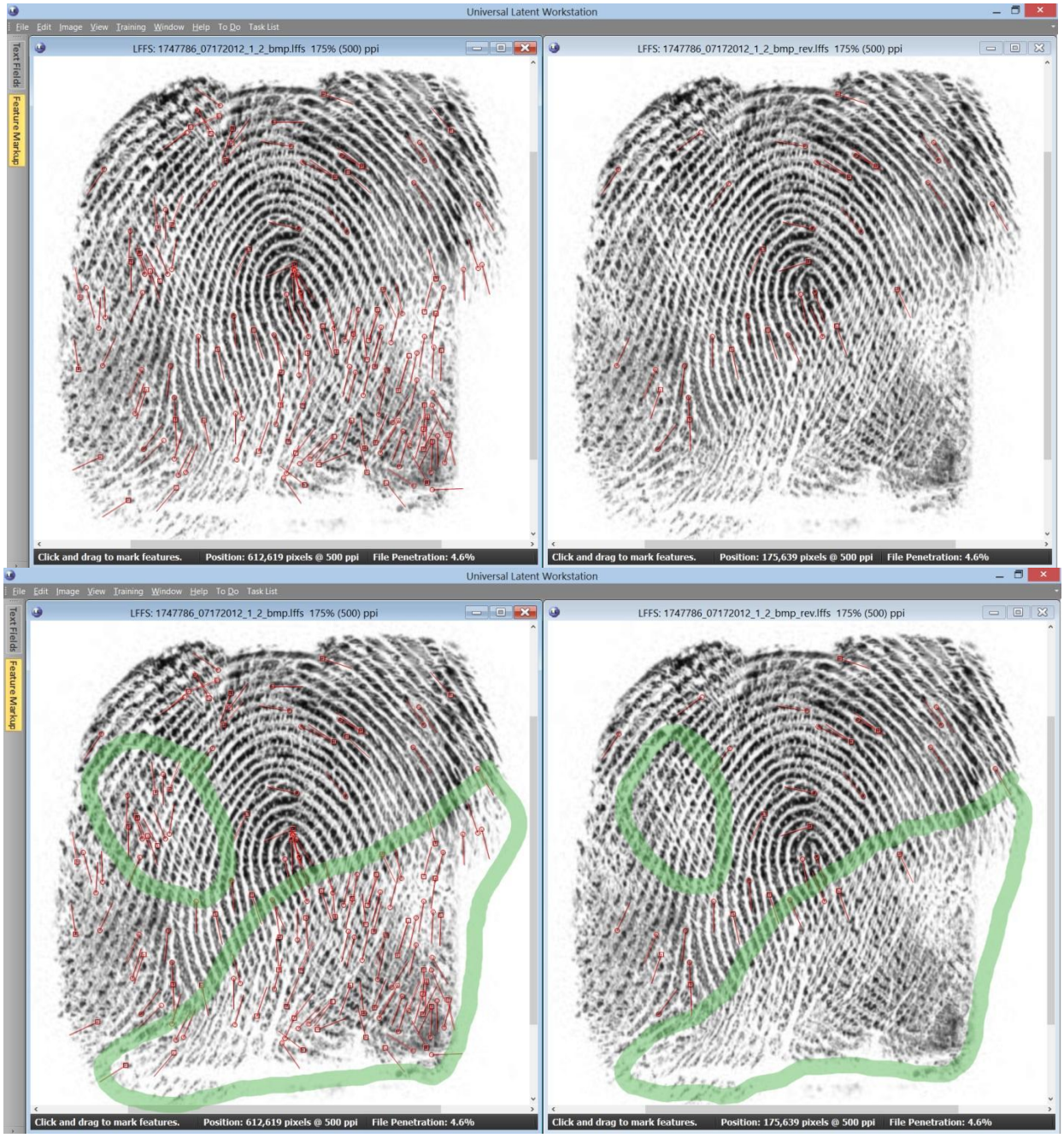

Figure 12: False Minutiae Creasing (SEEK)
False minutiae in a heavily creased fingerprint before and after markup revision. Diagram of affected areas highlighted in green.

5.2.2 Contrast Distortion

Several images from the SEEK II dataset displayed both heavy and light contrast issues, which were factors in the appearance of both false and/or incorrect minutiae placement.

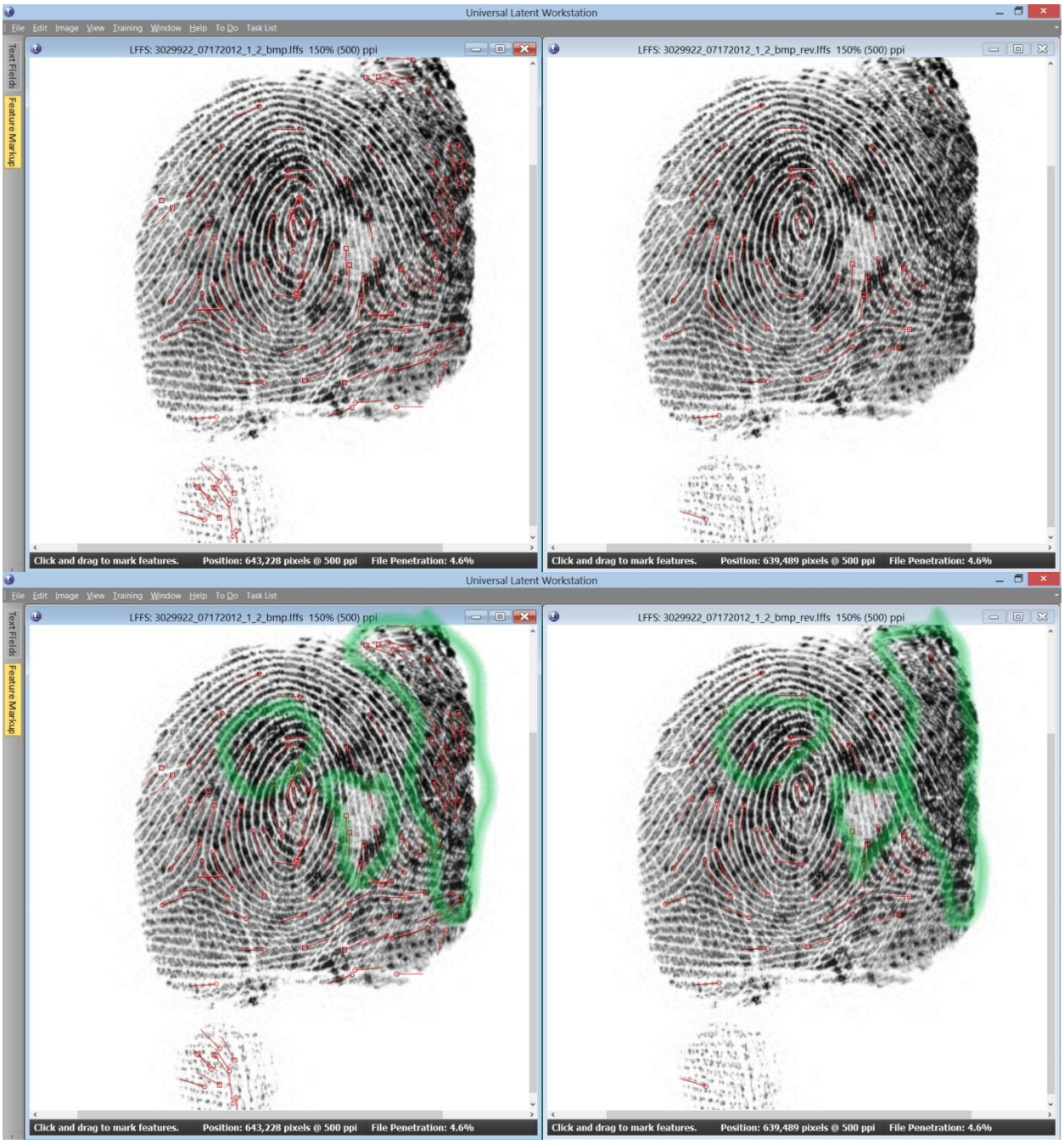

Figure 13: Contrast Distortion (SEEK)
Both heavy and light contrast distortion before and after markup revision. Diagram of affected areas highlighted in green.

5.2.3 Incomplete Capture

Several images from the SEEK II dataset were observed to be partially captured and/or contained void areas that were absent of friction ridge detail.

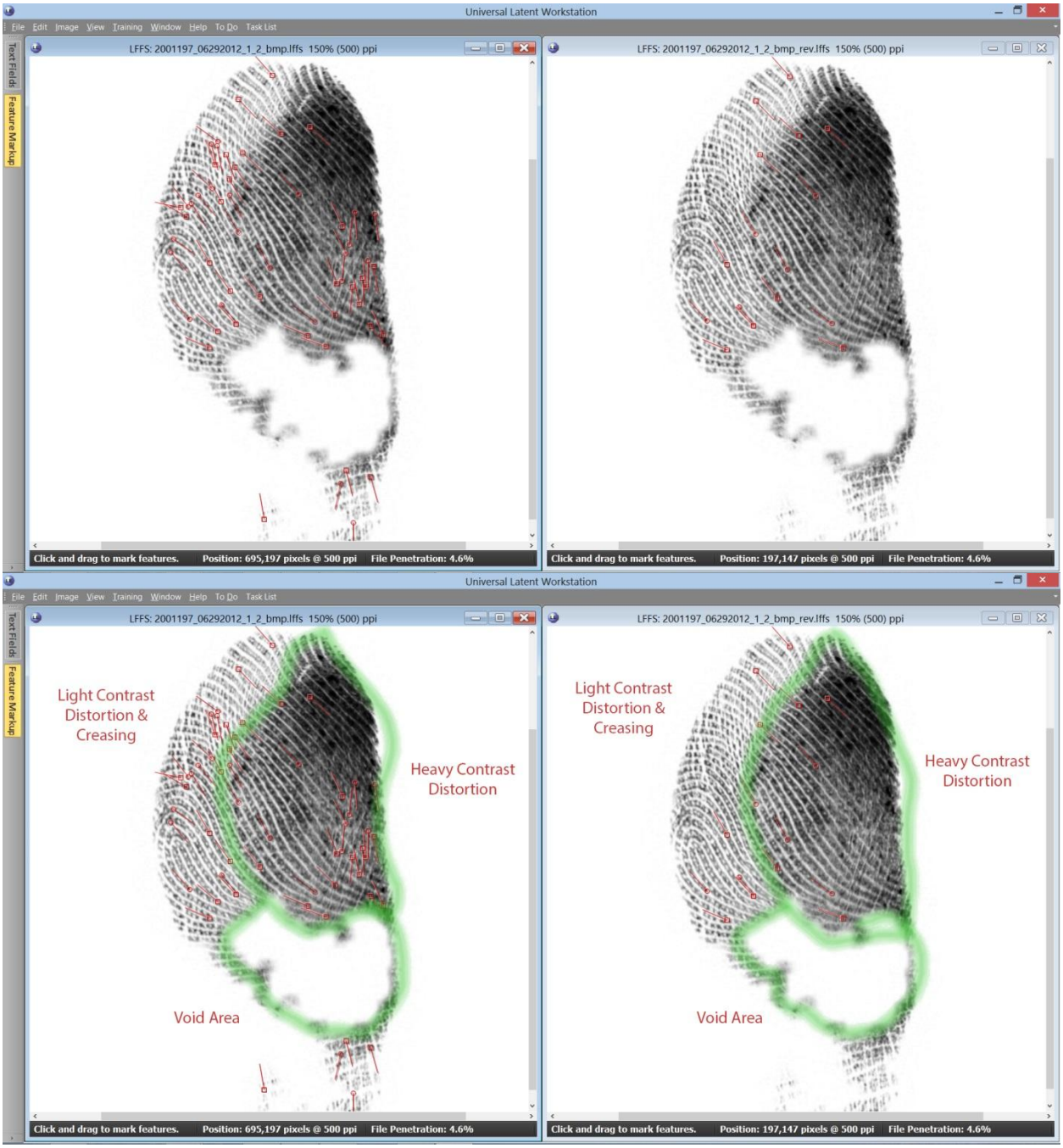

Figure 14: Incomplete Capture (SEEK)
Incomplete capture, void area, creasing and light and heavy contrast distortion before and after markup revision. Diagram of affected areas highlighted in green.

5.3.4 False/Incorrect Minutiae

Every single image in the SEEK II dataset was observed to have at least one or more incidents of false minutiae and/or incorrect minutiae type and/or incorrect minutiae placement.

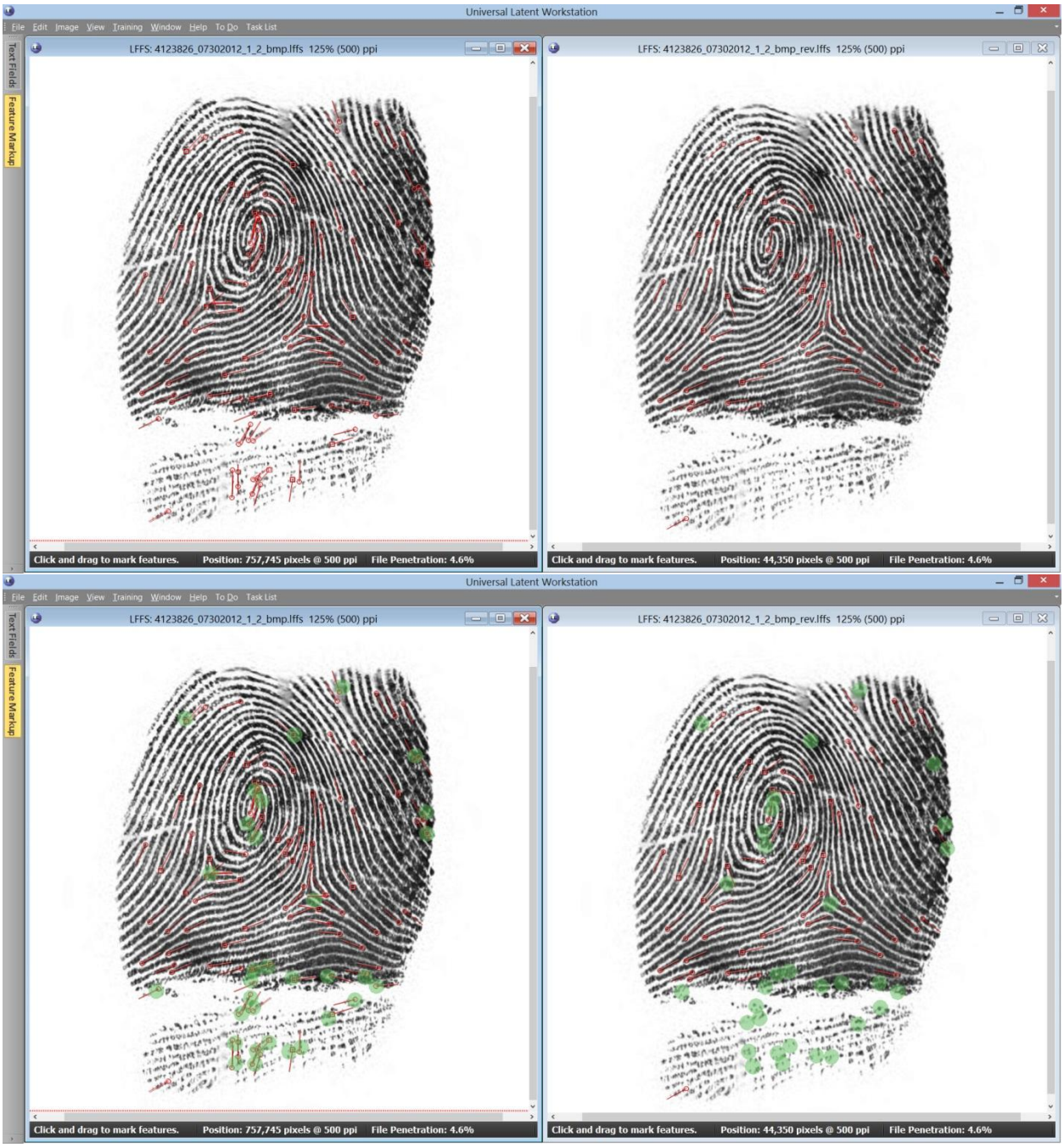

Figure 15: False/Incorrect Minutiae (SEEK)
False minutiae, incorrect minutiae type and incorrect minutiae placement before and after revision markup. Diagram of affected areas highlighted in green.

6.0 FLASHSCAN 3D D1 DATA SUBSET

6.1 Processing Metrics

As discussed in Section 3.1 Minutia Processing Metrics, the first 20 images of the FlashScan D1 dataset were processed and the minutiae count before and after for each image recorded. There was an average of **54 ± 21** minutiae before and **27 ± 8** after processing (**54 ± 16%** survived).

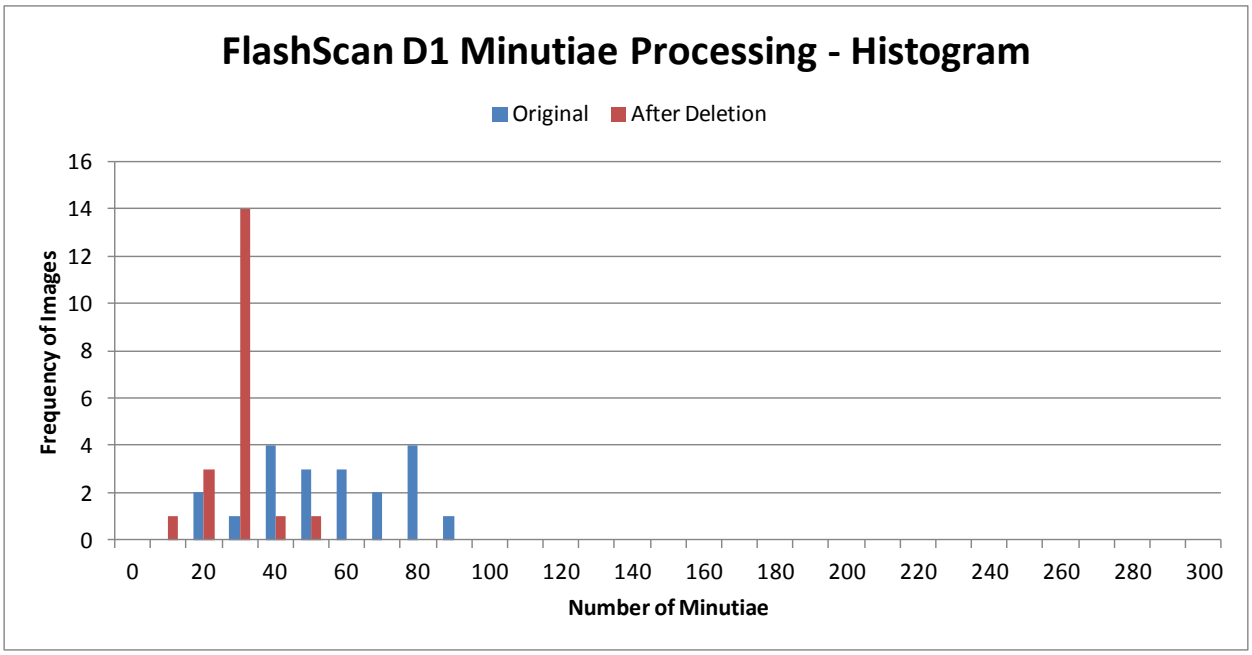

Figure 16: FlashScan D1 Minutiae Metrics – Histogram

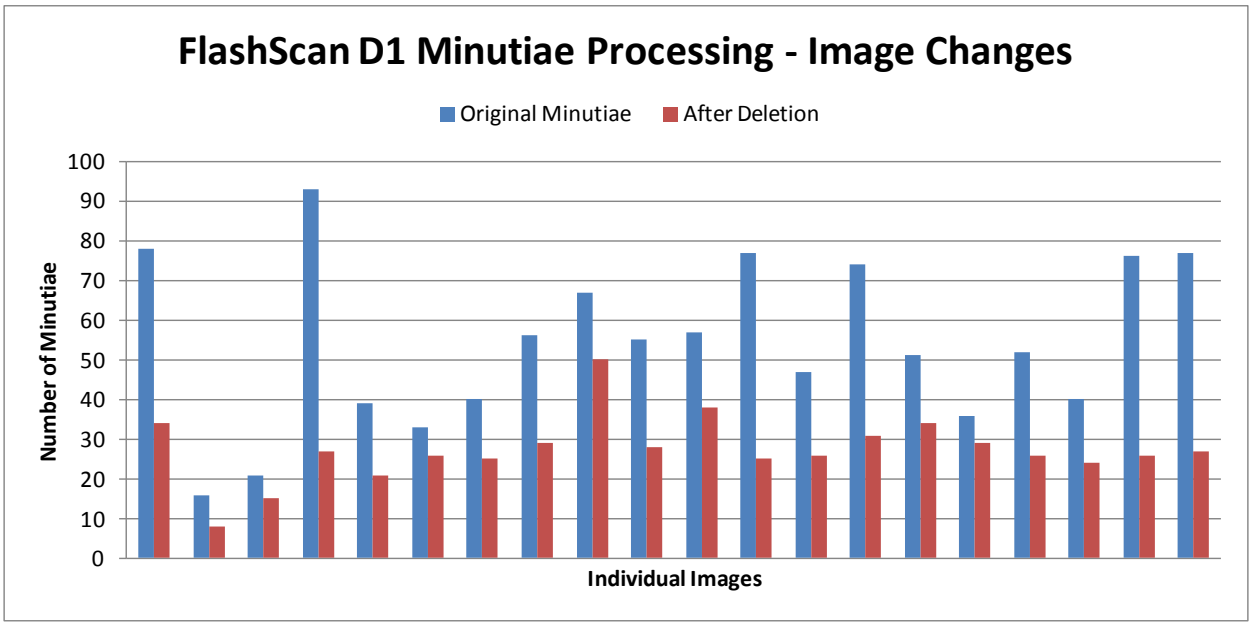

Figure 17: FlashScan D1 Minutiae Metrics – Image Changes

6.2 Image Artifacts

6.2.1 Distortion

Most images in the FlashScan D1 dataset were observed to have the following simultaneous distortion issues: stretching, pixilation and exaggerated features, which contributed to the appearance of fragmented and incipient-like ridges.

Figure 18: Distortion (FlashScan)
Various simultaneous distortion issues: stretching, pixilation and exaggerated features.

6.2.2. False/Incorrect Minutiae

Every single image in the FlashScan D1 dataset was observed to have at least one or more incidents of false minutiae and/or correct minutiae type and/or incorrect minutiae placement.

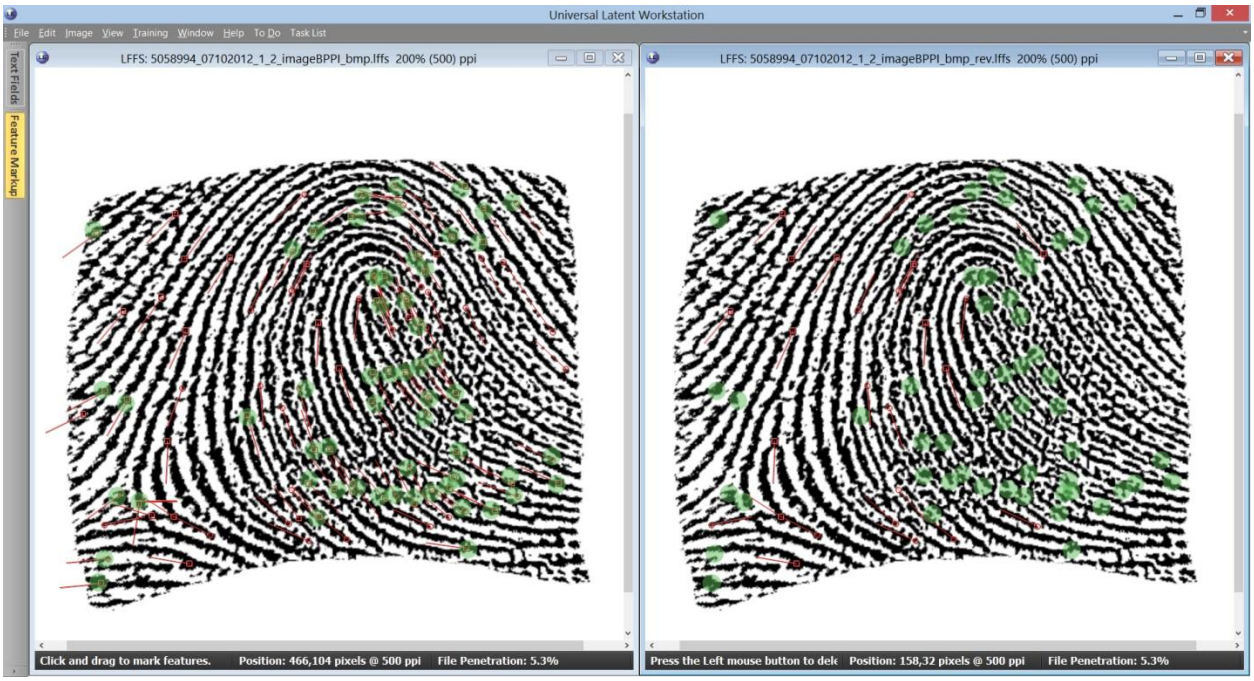

Figure 19: False/Incorrect Minutiae (FlashScan)
False minutiae, incorrect minutiae type and incorrect minutiae placement resulting from various simultaneous distortion issues before and after revision markup. Diagram of affected areas highlighted in green.

6.2.3 Incomplete Capture

Many images in the FlashScan D1 dataset were observed to be partially captured.

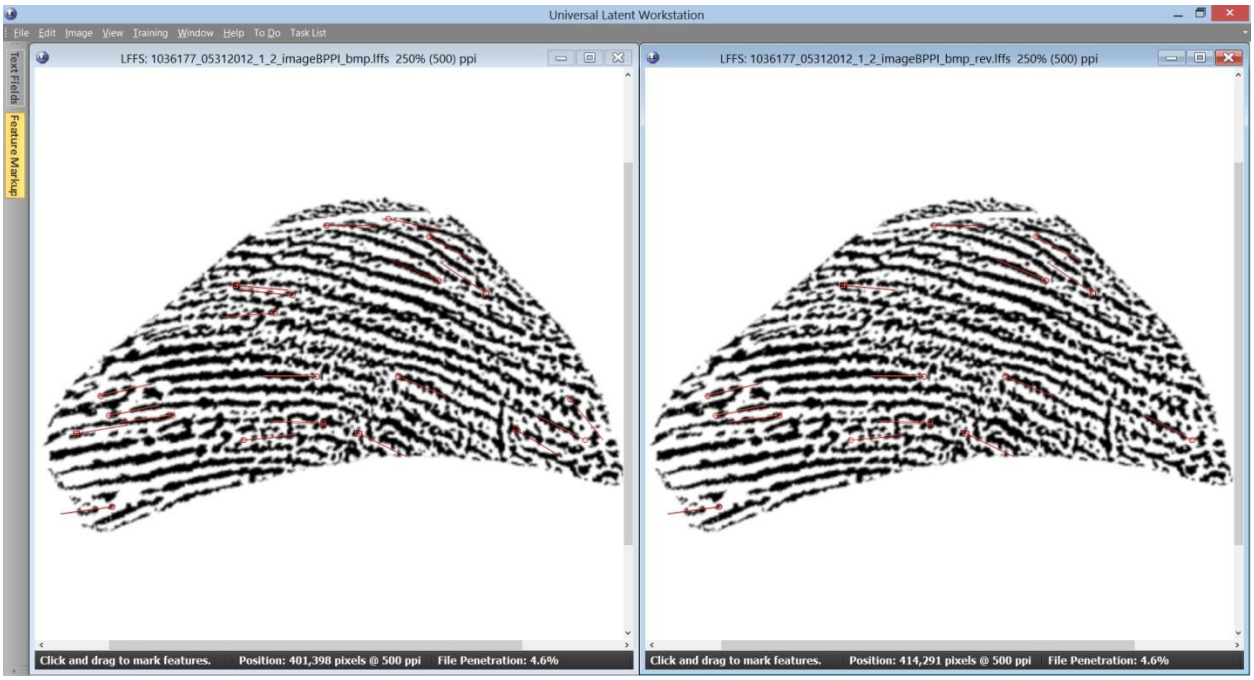

Figure 20: Incomplete Capture (FlashScan)
Incomplete capture before and after markup revision.

6.2.4 Rippled/Wavy Distortion

Several images in the FlashScan D1 dataset presented with a rippled/wavy distortion effect.

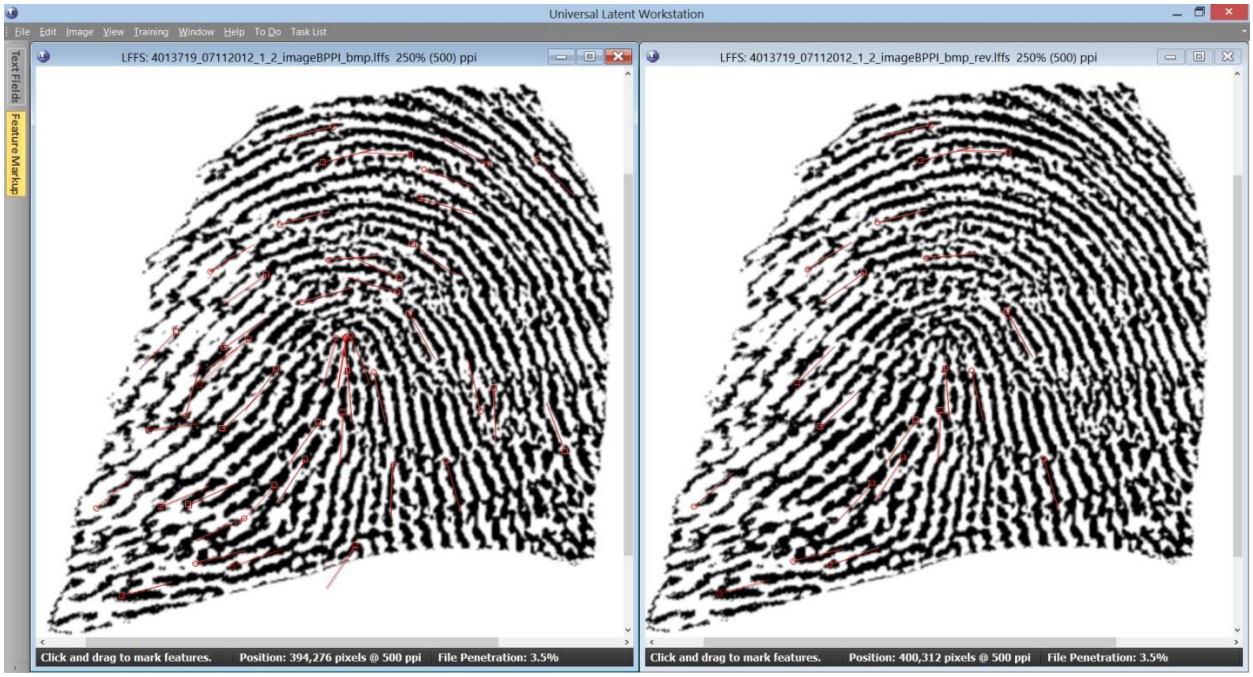

Figure 21: Rippled/Wavy Distortion (FlashScan)
Rippled/wavy distortion effect before and after markup revision.

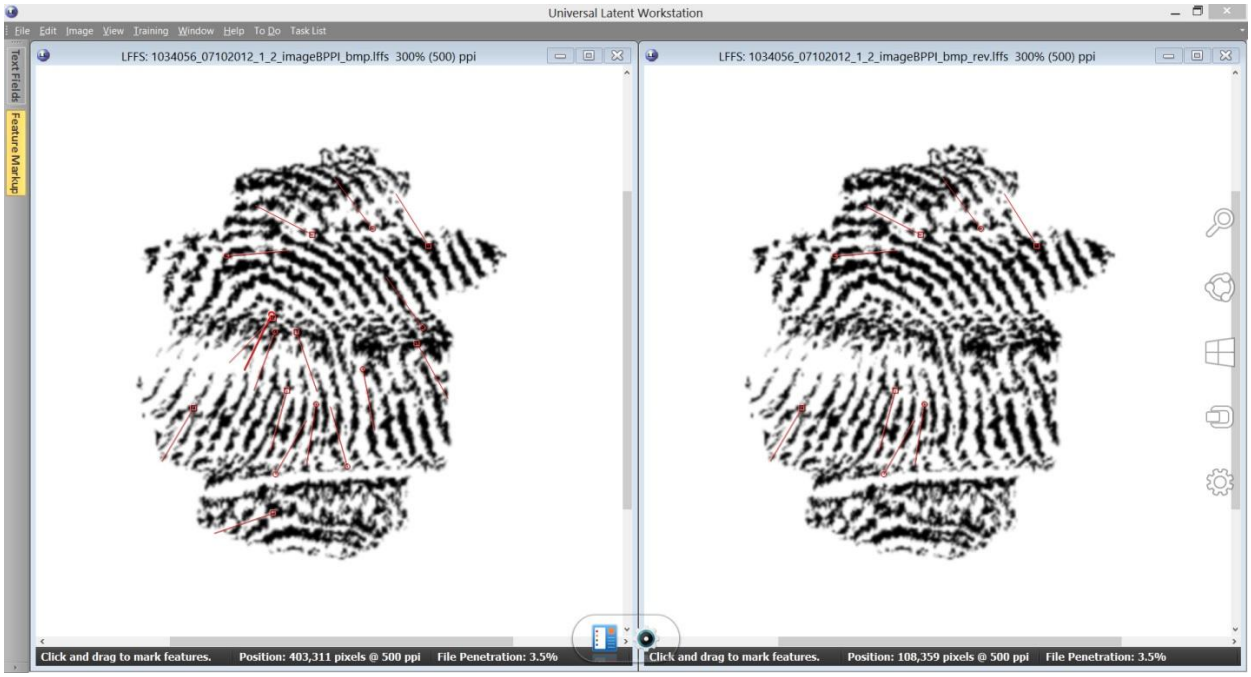

Figure 22: Rippled/Wavy Distortion with Incomplete Capture (FlashScan)
Rippled/wavy distortion effect with incomplete capture before and after markup revision.

7.0 TBS 3D ENROLL DATA SUBSET

7.1 Processing Metrics

As discussed in Section 3.1 Minutia Processing Metrics, the first 20 images of the TBS dataset were processed and the minutiae count before and after for each image recorded. There was an average of **158 ± 39** minutiae before and **60 ± 16** after processing (**40 ± 14%** survived).

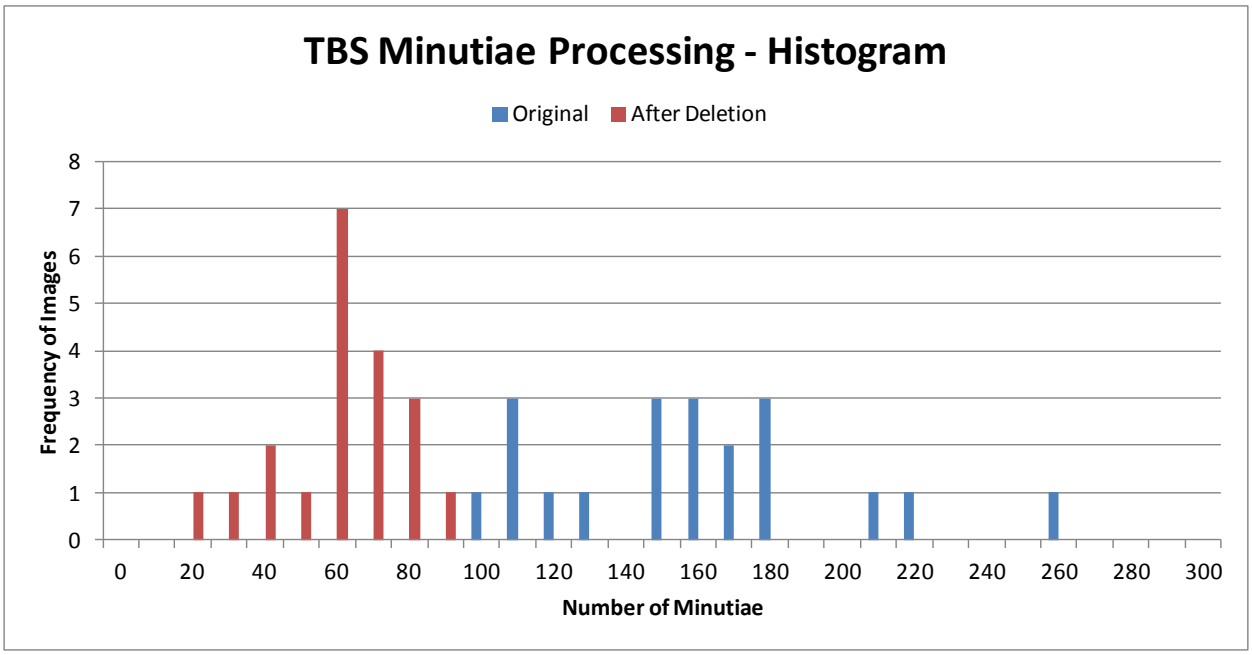

Figure 23: TBS Minutiae Metrics – Histogram

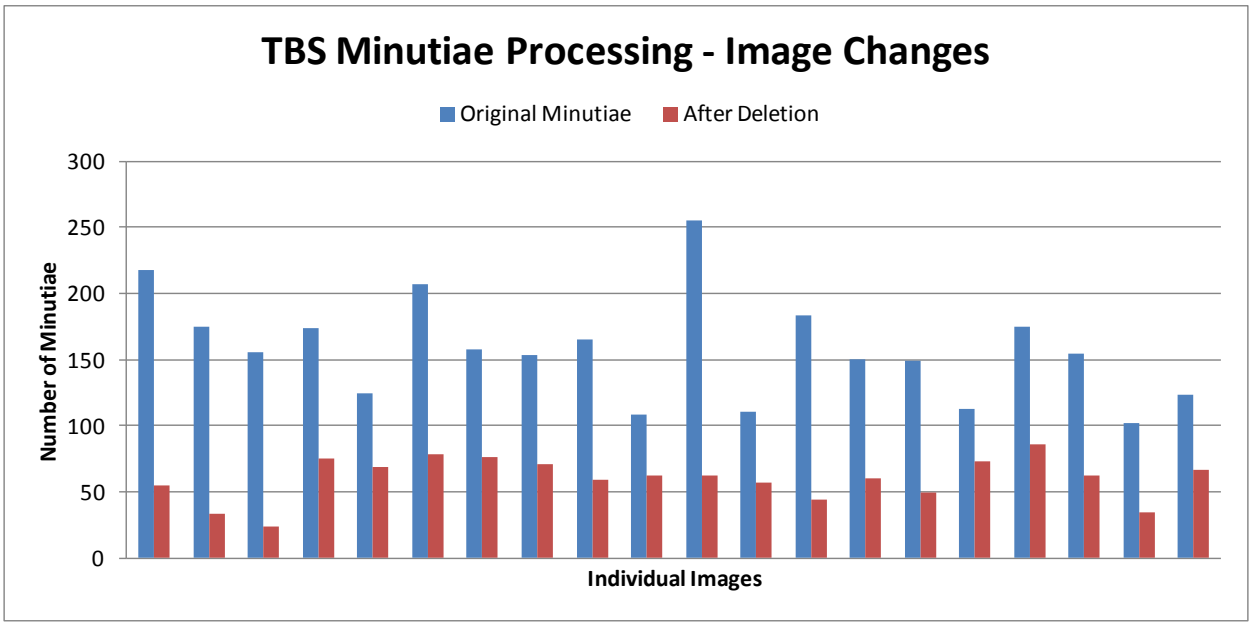

Figure 24: TBS Minutiae Metrics – Image Changes

7.2 Image Artifacts

7.2.1 False Minutiae Creasing

Several images from the TBS dataset contained false minutiae as a result of prolific creasing. It is uncertain whether these creases were truly organic or a result of the scanning process; however, it must be noted that false minutiae did not appear to be present in most of the images with truly organic creases.

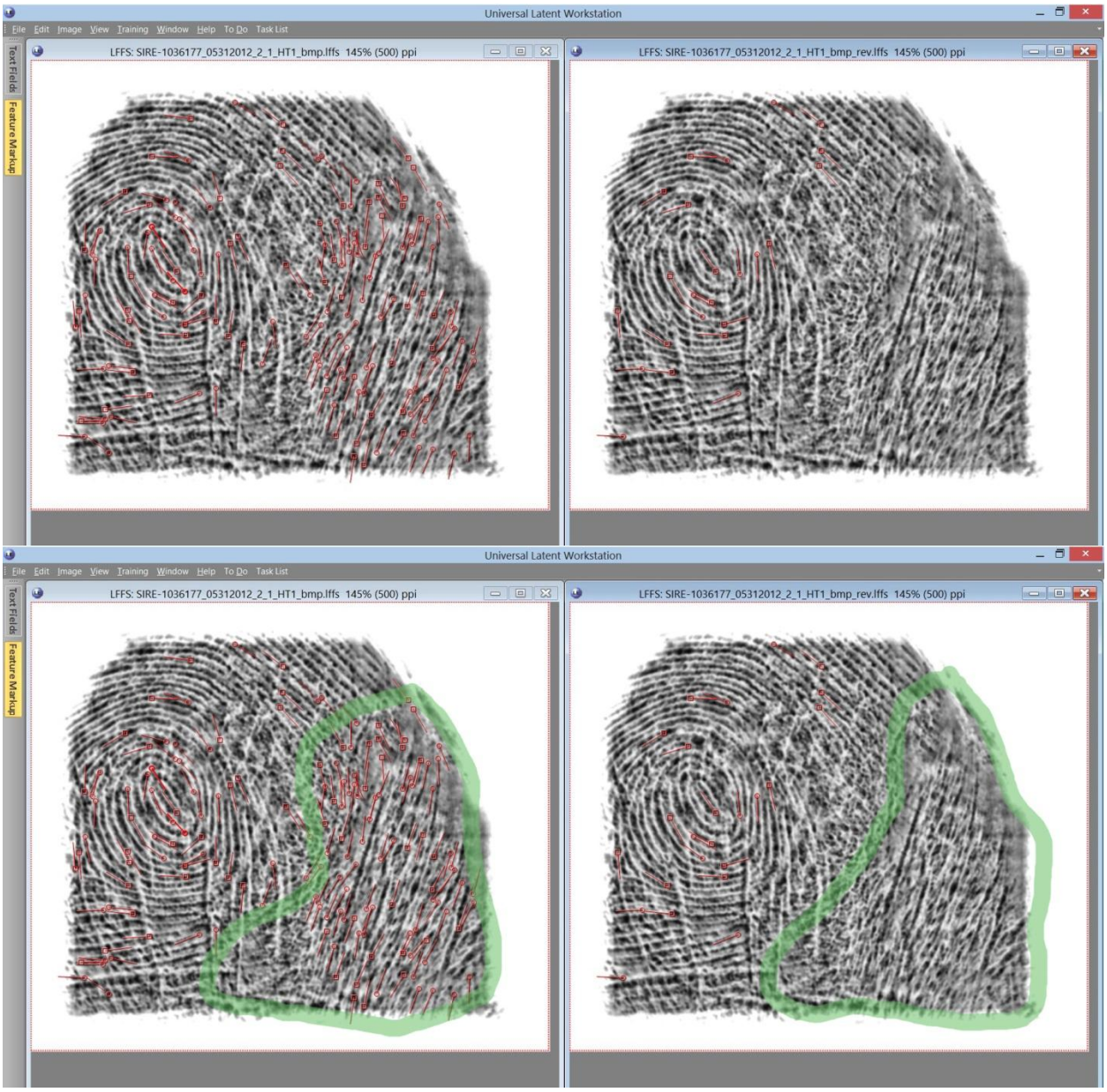

Figure 25: False Minutiae Creasing (TBS)

False minutiae in a heavily creased fingerprint before and after markup revision. Diagram of affected areas highlighted in green.

7.2.2 Blur and Tonal Distortion

Most images in the TBS dataset contained a significant amount of blur and tonal distortion. The tonal distortion was observed to affect the overall contrast of the images giving them a grayscale effect.

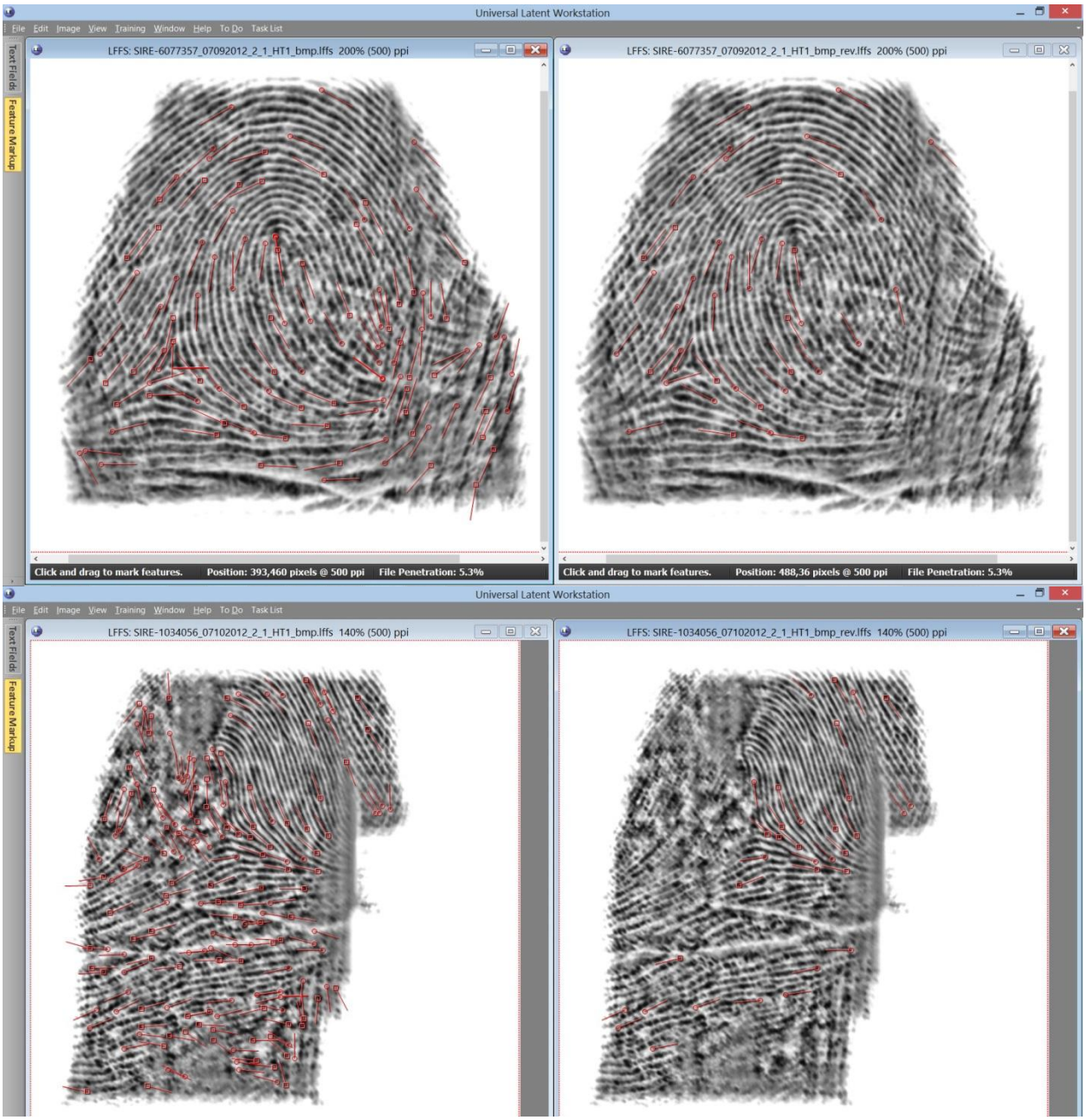

Figure 26: Blur and Tonal Distortion (TBS)
Blurred and tonally distorted images before and after markup revision.

7.2.3 Rippled/Wavy Distortion

Several images in the TBS dataset presented with a rippled/wavy distortion effect.

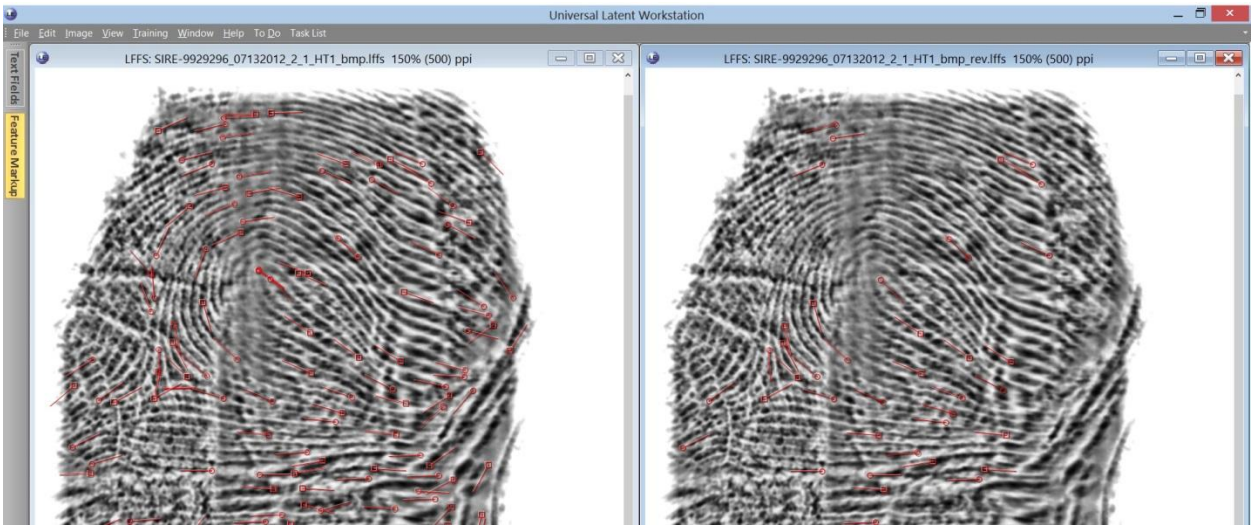

Figure 27: Blur and Tonal Distortion (TBS)
Rippled/wavy distortion effect with blurring, tonal distortion and creasing before and after markup revision.

7.2.4 False/Incorrect Minutiae

Every single image in the TBS dataset was observed to have at least one or more incidents of false minutiae and/or incorrect minutiae type and/or incorrect minutiae placement.

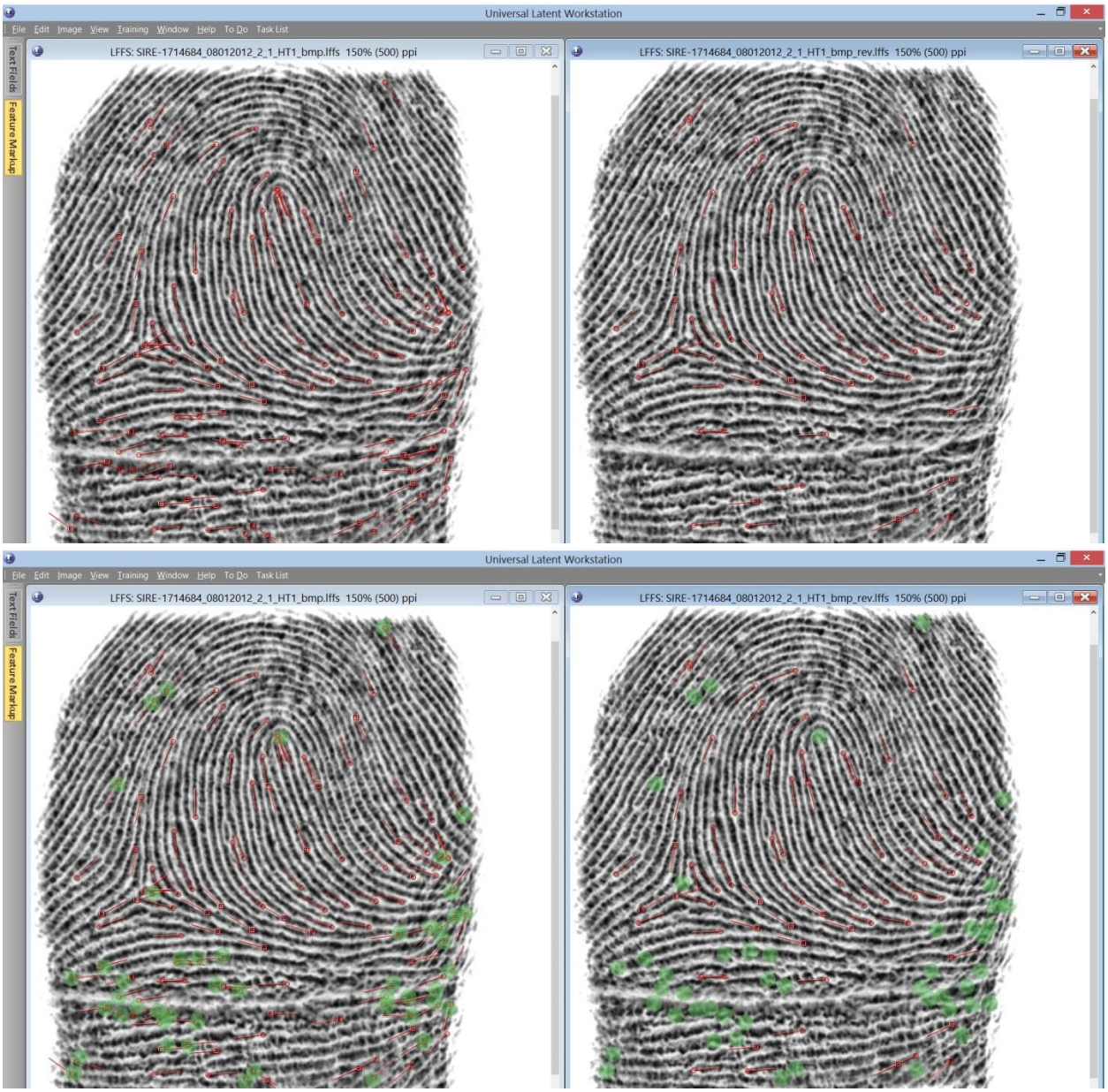

Figure 28: False/Incorrect Minutiae (TBS)
False minutiae, incorrect minutiae type and incorrect minutiae placement before and after revision markup. Diagram of affected areas highlighted in green.

APPENDIX A: GLOSSARY OF TERMS

Definition of Terms [10]

Bifurcation – The point at which one friction ridge divides into two friction ridges.

Crease – A line or linear depression; grooves at the joints of the phalanges, at the junction of the digits and across the palmar and plantar surfaces that accommodate flexion.

Distortion – Variances in the reproduction of friction skin caused by pressure, movement, force, contact surface, etc.

Dot – An isolated ridge unit whose length approximates its width in size.

Edgeoscopy (edge detail) – Study of the morphological characteristics of friction ridges; contour or shape of the edges of friction ridges.

Ending ridge or ridge ending – A single friction ridge that terminates within the friction ridge structure.

Friction ridge or ridge – A raised portion of the epidermis on the palmar or plantar skin, consisting of one or more connected ridge units of friction ridge skin.

Friction ridge detail (morphology) – An area comprised of the combination of ridge flow, ridge characteristics, and ridge structure.

Incipient ridge – A friction ridge not fully developed which may appear shorter and thinner in appearance than fully developed friction ridges (interstitial, nascent).

Level 1 detail – Friction ridge flow and general morphological information.

Level 2 detail – Individual friction ridge paths and friction ridge events, e.g., bifurcations, ending ridges, dots.

Level 3 detail – Friction ridge dimensional attributes, e.g., width, edge shapes, and pores.

Pattern types – The designation of friction ridge skin into basic categories of general shapes.

Qualitative (quality) – The clarity of information contained within a friction ridge impression.

Quantitative (quantity) – The amount of information contained within a friction ridge impression.

APPENDIX B: ACRONYMS, ABBREVIATIONS, AND REFERENCES

B.1 Acronyms and Abbreviations

ACRONYM	DESCRIPTION
ACE-V	Analyze, Compare, Evaluate, and Verify
AM	After Minutiae
ANSI	American National Standards Institute
ASD(R&E)	Assistant Secretary of Defense for Research and Engineering
AT&L	Acquisition, Technology, and Logistics
CFP	Contactless Fingerprint
CFPv1	Contactless Fingerprint Collection, Round 1
CLPE	Certified Latent Print Examiner
CMR2	Cross Match Guardian R2
CoE	Center of Excellence
DOJ	Department of Justice
EBTS	Electronic Biometrics Transmission Specification
EFS	Extended Feature Set
LFFS	Latent Friction Ridge Features Search
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NLECTC	National Law Enforcement and Corrections Technology Center
OM	Original Minutiae
OSD	Office of the Secretary of Defense
Ppi	Pixels per inch
QSP2	Quick Search Profile 2
R&D	Research and Development
SDK	Software Development Kit
SSBT	Sensor, Surveillance, and Biometric Technologies
StdDev	Standard Deviation
TBS	Touchless Biometric Systems
ULW	Universal Latent Workstation
WVU	West Virginia University

B.2 References

[1] ManTech Advanced Systems International (MASI) and Azimuth, Inc.; *Evaluation of Contact versus Contactless Fingerprint Data;* https://www.ncjrs.gov/pdffiles1/nij/grants/245146.pdf (January 23, 2014).

[2] NLECTC; *Sensor, Surveillance, and Biometric Technologies Center of Excellence;* https://www.justnet.org/our_centers/coes/sensor-tce.html (Accessed April 2, 2014).

[3] WVU, *Non-Contact Multi-Sensor Fingerprint Collection,* https://www.ncjrs.gov/pdffiles1/nij/grants/246711.pdf (August 2012).

[4] Neurotechnology; *MegaMatcher 4.5, VeriFinger 6.7, VeriLook 5.4, VeriEye 2.7 and VeriSpeak 2.0 SDK* (March 31, 2014).

[5] NIST, *ANSI/NIST-ITL 1-2011 NIST Special Publication 500-290 Rev1 (2013) Data Format for the Interchange of Fingerprint, Facial & Other Biometric Information,* http://biometrics.nist.gov/cs_links/standard/ansi_2012/Update-Final_Approved_Version.pdf (December 2013).

[6] FBI CJIS, *IAFIS-DOC-01078-9.3 Electronic Biometric Transmission Specification (EBTS) version 9.3* (December 9, 2011).

[7] NIST, *NIST Special Publication 1151 Markup Instructions for Extended Friction Ridge Features,* http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1151.pdf (January 2013).

[8] Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST); *Standard for the Documentation of Analysis, Comparison, Evaluation, and Verification (ACE-V) (Latent);* http://www.swgfast.org/documents/documentation/121124_Standard-Documentation-ACE-V_2.0.pdf (September 1, 2012).

[9] Peter E. Peterson, et. al; FBI; "Latent Prints: A Perspective on the State of the Science," *Forensic Science Communication* Volume 11, Number 4; http://www.fbi.gov/about-us/lab/forensic-science-communications/review/2009_10_review01.htm (October 2009).

[10] SWGFAST; *SWGFAST Consolidated Glossary, ver. 1*; http://www.swgfast.org/documents/glossary/030909_Glossary-Consolidated_ver_1.pdf (September 9, 2003).