SLAPSEGII

Slap Fingerprint Segmentation Evaluation II

Draft Testing Plan

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Abstract

In 2004, NIST conducted a fingerprint slap segmentation study [1] to assess the state-of-the-art in fingerprint segmentation technology. Given the development of new technology it has become necessary to reassess the current state-of-the-art of segmentation algorithms. SlapSegII will give providers of this technology the opportunity to participate multiple times as their technology improves and compare their results to previous results on a fixed standard database. The SlapSegII testing strategy, evaluation data, and measure of successful segmentation are discussed in detail in this testing plan.

1. Introduction/Background

Fingerprint data is collected and maintained in the form of Ten-print cards or Identification Flats (ID Flats). Traditional Ten-print cards are comprised of the rolled impressions of the ten fingers as well as four slap impressions: the left slap (four fingers of the left hand), the right slap (the four fingers of the right hand) and the thumb slap (the left and right thumbs). Slaps are taken by pressing the four fingers of one hand onto a scanner or fingerprint card simultaneously. The Ten-print card slaps whether scanned inked cards or live-scan capture are also referred to in this document as 2 inch data which refers to the height of the capture area for the fingerprint slaps. ID Flats are Ten-print fingerprint records which are constructed by capturing three discrete impressions: left slap, right slap, and both thumbs together. For this document the ID Flats are data that was captured on new live-scan devices that use a larger platen that is 3 inches in height so this data is also referred to as 3 inch data.

Currently the Federal Bureau of Investigation (FBI) receives the majority of their fingerprint submissions electronically from live-scan devices, however, hundreds of millions of legacy fingerprint transactions are stored that were originally taken on paper cards and electronically converted. The Department of State (DOS) and Department of Homeland (DHS) US-VISIT program are migrating from 2 finger capture to 10 print ID Flats capture so the ability to evaluate and improve segmentation technology on this type of data will have a significant impact on those agencies.

2. Purpose of Slap Fingerprint Segmentation (SlapSeg)

Slap fingerprints are noted for the speed at which they can be documented and processed. However, a slap record is an image of multiple fingers. Fingerprint images must be matched against individual fingerprint images, not an image of a group of fingers. Thus, it is necessary to quickly and accurately separate, or segment, the grouped image of prints into individual fingerprint images which can be used for matching.

2.1. Definition

Slap segmentation is the process by which a single image containing four fingerprint images is divided into four images of the individual fingers or by finding the fingerprint segmentation positions and using them to separate the image into individual images at a later date. The term fingerprint segmentation positions refer to the expected positions of each of the four fingers and thumb of each hand relative to an adjacent finger of the hand. The fingerprint segmentation positions are defined in the ANSI/NIST-ITL 1-2007 data transmission standard (type-14 record) [4] for non-rotated segmentation boxes as the x-coordinate of the left and right edge and the y-coordinate of the top and bottom edge of the segmentation box. For rotated fingerprint images, segmentation positions are the x,y coordinates of the four corners of the rotated segmentation box. For this evaluation they will be in the follow order: top-left corner, top-right, bottom-left, and bottom-right. Fingers are conventionally numbered as positions 1 and 6 (thumbs on the right and left hands, respectively), 2 and 7 (index fingers), 3 and 8 (middle fingers), 4 and 9 (ring fingers), and 5 and 10 (small fingers). Accurately labeling each finger is imperative for future matching efforts as well as the ability to correctly detect when fingers are not present in the image.

2.2. Issues

Slap segmentation can prove difficult due to a variety of scenarios. The most common challenge scenarios include fingerprints that are not clearly separated in an image, a fingerprint which appears as multiple images in a slap, background noise, the “halo” effect, and rotation. Many of these problems are the same as those that existed in the SlapSeg04 evaluation but the use of newer 3 inch platen capture devices can reduce problems such as finger spacing and rotation.

Figure 1. Middle fingers touching in slap.

Slap segmentation can be adversely affected by fingers that are not clearly separated in an image (See Figure 1), which could be due to finger placement at the time of capture. It is also possible that two neighboring fingerprints may have been over inked or too wet/oily at the time of capture, in which case a down sampling or an improper threshold may result in the fingerprints being detected as single component. However, the single component should not be split solely due to the large width of the detected component. The preferred method for splitting the component depends on the width of the component, the number of components detected, and the geometric relationship of the component to the other components.

At the opposite end of the spectrum, an excessively dry or under inked finger or a fingerprint captured using uneven pressure may be detected as several components due to down sampling or improper thresholding. (See Figure 2). Whether to merge or delete these components depends on the relationship between each sub component and the rest of the components. Segmentation algorithms often use contrast equalization to enhance ridge detail and allow for better segmentation. Though this process can sometimes improve the matching quality of the segmented fingerprint, it sometimes has the opposite effect. However, SlapSegII will not judge the effect these changes have to fingerprint image's quality in regards to matching as SlapSegII will focus on segmentation, not matching.

Figure 2. Low Contrast slap image.

Background noise such as extraneous print lines, printed letters, smudges, etc near the boundary of the slap print pose an additional challenge for segmentation. (See Figure 3.) "Noise", which may also be caused by dirt on the platen surface of the scanner, is most problematic in low contrast images.

Figure 3. "Noisy" slap image.

The "Halo" affect can make segmentation difficult as it introduces noise to the image. (See Figure 4.) The "Halo" affect is a moisture build up on platen surface of the scanner due to temperature variations (i.e. a warm hand being placed on a cool scanning surface).

Figure 4. Moisture/Condensation on the platen surface.

Image rotation poses an additional problem when a scanner with a two inch high scanning surface is used, as well as in some older paper data which has been scanned electronically. (See Figure 5.)

Figure 5. Slap rotation.

Amputated fingers could also pose a problem during the segmentation process. Livescan capture devices should correctly identify this problem during the enrollment process, however older devices may not have captured this information and electronically converted fingerprint cards may not have the proper flags for amputation. The segmentation software may incorrectly segment an image based on missing or amputated fingers.

Often the right and left little finger are not captured or only partially captured during the slap enrollment process. Vendors may fail to find these partial little fingers or have trouble processing transactions without little fingers. While this is actually a livescan capture issue versus a segmentation issue, the resulting image can pose challenges to the segmentor.

3. SlapSeg 2004

SlapSeg04 [1] was conducted to assess the accuracy of existing slap segmentation algorithms in segmenting slap fingerprint images into individual fingerprint images, using a variety of operational-quality slap fingerprints. The study was conducted by the National Institute of Standards and Technology (NIST) on behalf of the Department of Justice (DOJ) Justice Management Division (JMD), IDENT/IAFIS Integration Project, with the support of the US-VISIT Program Office of the Department of Homeland Security (DHS) and the Federal Bureau of Investigation (FBI).

The study, which was conducted between October and December of 2004, used rolled images to match against the segmented slaps as the measure of segmentation success. This required manual checking to verify the results of each vendor as a low quality image may have segmented correctly without matching to the rolled image. The study examined records from about thirty thousand subjects from seven different operational datasets, none of which was three inch platen fingerprint data. SlapSeg04 incorporated several subtly different objectives including measurement of the accuracy of state-of-the-art slap segmentation software, assessment of the practicality of segmenting operational quality slap fingerprints, determination of the factors that cause slap segmentation and matching to fail, and assessment of the ability of segmentation algorithms to detect when segmentation was successful.

4. SlapSegII

SlapSegII will be conducted by NIST in order to provide the ability to assess the current state-of-the-art in slap segmentation technology. SlapSegII will give vendors the opportunity to participate multiple times as their technology improves and compare their results to previous results on the same dataset.

The study is sponsored by the FBI and DOS. The sponsors require the ability to test on large volumes of Sensitive But Unclassified (SBU) data. The FBI is accepting submissions consisting only of slap data, while DOS/DHS are currently migrating from 2 finger captures to ten finger captures for its US-VISIT program. The most efficient method for capturing ten fingers is slap images. Thus the sponsors will benefit from knowing what the current state of the art is in slap segmentation technology. Vendors will also benefit from the study as they will gain the knowledge of how their segmentation implementation will perform on a large dataset of operational quality law enforcement data. Thus, the study can prove extremely critical for improving segmentation technology.

4.1. Testing Strategy

NIST intends to use a measure of successful slap segmentation for SlapSegII that requires minimal manual verification of segmented slaps and does not rely on the ability to match segmented slap images. This success measure is based on comparing segmentor output with “ground truth” segmentation coordinates. In order to prove effective, it is imperative to have a controlled test location, submission process, and validation data, as well as a clear understanding of the input and expected output.

4.2. Test Location

All testing will be conducted at the NIST laboratory in Gaithersburg, MD. The lab responds to needs for measurement methods, tools, data, and technology. NIST researchers collaborate with colleagues in industry, academic institutions, and other government agencies. The result is research that advances the nation's technology infrastructure and is needed by U.S. industry to continually improve technology and services.

4.3. Who Should Participate

Makers of commercially available slap fingerprint segmentation software are invited to participate in the Slap Fingerprint Segmentation Evaluation II. In addition, companies, research organizations, or universities that have developed mature prototype or research slap fingerprint segmentation software are invited to participate. It is important to note that the segmentation software need not be "operational," nor a production system, nor commercially available. However, the system must, at a minimum, be a stable implementation capable of being "wrapped" (formatted) in the specification that National Institute of Standards and Technology (NIST) has published for this evaluation (Section 4 of this document). Additionally, anonymous participation will not be permitted. The results of the evaluation of the software will be published with attribution to the participating organizations.

4.4. Submission Process

In order to simplify the submission process, NIST will adhere to specific guidelines and processes for vendor submissions. NIST will write and maintain the control software. Vendors will submit compiled command line executables that do not use any graphical user interface (GUI) and will run on either Red Hat Enterprise Linux 5 or Windows Server 2003 operating systems[1]. Any data generated or obtained during the SlapSegII evaluations, as well as any documentation required by the Government from the participants, becomes the property of the Government. Participants will not possess a proprietary interest in the data and/or submitted documentation.

4.5. Application Process

In order to request participation in SlapSegII, potential participants must complete and submit the Application to Participate in SlapSegII (will be made available on the website). Incomplete forms will not be accepted. When completing the application, the Responsible Party must be an individual with the authority to commit the organization to the terms in this document, and the Point of Contact must be an individual with detailed knowledge of the system to be considered for evaluation.

Participants may withdraw from the SlapSegII evaluations at any time before the software to be evaluated is received by NIST, without their participation and withdrawal being documented in the SlapSegII Evaluation Report.

[1] Specific hardware and software products identified in this plan will used in order to perform the evaluations described in this document. In no case does identification of any commercial product, trade name, or vendor, imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products and equipment identified are necessarily the best available for the purpose.

Upon receipt of the signed form by NIST, the organization will be classified as a “Participant”. NIST must receive the form by the due date described in the SlapSegII Calendar, as posted on the SlapSegII website for inclusion in the initial evaluation report. Registered participants should then download the small Validation Dataset when it is available on the website.

4.6. Points of Contact

The SlapSegII Liaison is the government point of contact for SlapSegII. All correspondence should be directed to slapseg@nist.gov, which will be received by the SlapSegII Liaison and other SlapSegII personnel. Any correspondences may be posted on the FAQ (Frequently Asked Questions) area of the SlapSegII website at the discretion of the SlapSegII Liaison. The identity of those persons or organizations whose correspondences lead to FAQ postings will not be made public in the FAQ.

4.7. Validation Data

In order to minimize the variability introduced to testing by the physical differences in vendor hardware versus NIST hardware, NIST will provide sample/validation data to the vendors prior to testing. This validation data will be used to ensure that the software produces the same results on vendor computers and NIST computers. Thus ensuring the software being tested will produce the required data format during testing.

4.7.1. Access to SlapSegII Validation Data

The SlapSegII Validation Data will be supplied to Participants to assist in preparing for SlapSegII. The fingerprints in the SlapSegII Validation Data are representative of the SlapSegII Test Data only in format. Image quality, collection device, and other characteristics may vary between the Validation and Test Datasets.

4.7.2. Validation and Submission Process

Prior to submission of their SDK the participant needs to verify that their software executes on the validation data and produces segmentation information in the required format.

After the Participant has executed his software on the Validation Data, the output of the validation data must be submitted to NIST along with the SDK. Software can be sent by email (**file must be encrypted using encryption key provided by NIST, procedures will be posted on the SlapSegII website.**) to slapseg@nist.gov, or on CD (recommend encrypting the files on the CD) to:

Slap Fingerprint Segmentation Evaluation II (SlapSegII) Liaison
National Institute of Standards and Technology
Information Access Division (894)
100 Bureau Drive, Stop 8940
Gaithersburg, MD 20899-8940

Software submitted must be compliant with the section 4 of the SlapSegII Documentation, as posted on the SlapSegII website at

http://fingerprint.nist.gov/SlapSegII/slapsegII.pdf

Upon receipt of the SDK and validation output, NIST will attempt to reproduce the output by executing the SDK on the validation data using a NIST computer. In the event of disagreement in the output, if the software is found to be non-functional or non-compliant with section 4 of this document, or the validation dataset results cannot be replicated by NIST, participants will be notified with a detailed description of the problem(s) and given a reasonable opportunity to resubmit (as time allows) according to the discretion of the SlapSegII Liaison.

4.8. Application Inputs

Slap Fingerprint Segmentation Evaluation II will investigate the accuracy of fingerprint image segmentation systems for use with multi-finger slap images. These slap images will consist of both 2 inch slap data (fingerprint are rotated) and 3 inch slap data (no rotation). The 2 inch data contains left and right four finger slap images that are live-scan and rescanned ink. The 3 inch data contains left and right four finger slap images as well as slap impressions containing both left and right thumbs. All 3 inch data is live-scan.

The submitted segmentation application is assumed to run on Windows Server 2003 or Red Hat Linux Enterprise 5.0, on x86 platforms[2]. Other options must be approved by the Test Liaison. The application must have a command-line interface as specified in this document; no other user interface is permissible.

The segmentation application must be capable of taking as input an uncompressed raw slap image, and outputting the segmentation coordinates as specified in this document.

[2] Specific hardware and software products identified in this plan will used in order to perform the evaluations described in this document. In no case does identification of any commercial product, trade name, or vendor, imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products and equipment identified are necessarily the best available for the purpose.

4.8.1. Slap Image Files

The segmentation application must be capable of processing multi-finger slap images stored raw pixel data files.

Syntactically correct samples will be made available on the website.

4.8.1.1. Resolution and Dimensions

All images for this test shall be 500 PPI resolution (horizontal and vertical). The dimension of the 3 inch slap images are 1576 x 1572 pixels (80mm x79.9mm, 3.15in x 3.14in). The majority of the 2 inch slap images are 1600 x 950 pixels (81.3mm x 48.3mm, 3.2in x 1.9in) but may be as large as 1600 x 1000 pixels.

4.8.1.2. Slap Image Filenames

Multi-finger slap image files shall be specified in the command line either by relative pathnames, or fully-qualified pathnames. Unix-style forward slashes ("/") shall be used, not Windows-style backward slashes ("\"). For example,

```
/3inch/data/slap001.raw
```

The *root* filename is defined as the filename without the path or extension. For example,

```
slap001
```

Root filenames will be limited to alphanumeric characters and underscores. Symbolic links or Windows shortcuts will not be used.

4.8.1.3. Raw File Format

Raw 8-bit grayscale image files are canonically encoded with black equal to 0, white equal to 255, etc.; stored left to right, top to bottom, with one 8-bit byte per pixel. The number of bytes in a file is exactly the image width * image height, as measured in pixels; there is no header.

4.8.2. Input Parameters

The following information shall be provided as parameters to the segmentation application:

Identifier [-i]

> If this input is given the segmentation algorithm will return the software vendor's point of contact email address without performing any segmentation. This will be used to confirm that the correct segmentation algorithm is run for the testing vendor. Optionally, the vendor can provide version information after the email address.

Type [-t]

specifies the type of the fingerprint image: **2** (2 inch), **3** (3 inch).

Hand identifier[-h]

specifies **R** (right hand), **L** (left hand), or **T** (two thumb, 3 inch only) corresponding to the specified slap image.

Source [-s]

specifies the source of the fingerprint image: **L** (livescan), **P** (paper), or **U** (unspecified; could be livescan or paper).

The parameters (if present) will always be in the stated order. Parameters will be separated by spaces or tabs.

4.8.2.1. Example Command-line Usage

The following are examples of how the input parameters may be specified to the segmentation application (using "Unix-like" command-line usage syntax). In the following examples, items within "[ ]" are optional. The application should be named "ssIIseg" (Linux) or "ssIIseg.exe" (Windows).

Usages:

`ssIIseg –i`

`ssIIseg –t TYPE -h ID –s SOURCE image.raw WIDTH HEIGHT`

-i

Segmentation algorithm only returns vendor point of contact email address for confirmation that testing is linked to correct vendor. Optionally, version information can be provided after the email address.

-t TYPE

Slap image type (**2**=2 inch, **3**=3 inch, no other cases)

-h ID

Hand identifier (**R**=right, **L**=left, **T**=Two Thumbs) (no other cases; uppercase only)

-s SOURCE

Fingerprint image source (**L**=live-scan, **P**=paper, **U**=unspecified) (no other cases; uppercase only). 3 inch data will be all live-scan and 2 inch can be a mix of live-scan, paper, and unknown.

image.raw WIDTH HEIGHT

Raw image filename with height and width in pixels

Examples:

ssIIseg –i

ssIIseg –t 3 –h L –s L slap001.raw 1576 1572

4.9. Application Outputs

4.9.1. Segmentation Coordinates

The segmentation output for each input image will be multiple lines of text which contain the segmentation box coordinates for each expected finger in the slap image. The output coordinate format will be based on the type-14 record from ANSI/NIST-ITL 1-2007 [4].

For 2 inch images the output will be the x,y coordinates for all four corners of the segmentation box and the angle of rotation (theta) for the fingerprints in the image. The corner x,y coordinates will be listed in the following order: top-left, top-right, bottom-left, and bottom-right. The rotation angle will use positive for clockwise rotation and negative for counter-clockwise rotation and be given in degrees of rotation. Zero degrees will be at vertical. It is anticipated that the vertices form a rectangular segmentation box but it is not required in the way they are reported. For this evaluation the ground truth boxes are rotated rectangles, it is up to the reporting segmentation algorithm whether or not to report rectangular segmentation boxes for 2 inch slaps.

All 3 inch input data is assumed to be vertical/non-rotated and the segmentation should be the best fit vertical/non-rotated box for each finger in the slap image. The segmentation coordinates for the 3 inch slap will be the x-position of the left side, x-position of the right side, y-position of the top, and y-position of the bottom of the segmentation box. All x,y positions are from the top-left corner of the slap image.

The finger positions are the position codes defined in Table 12 of ANSI/NIST-ITL 1-2007 [4]:

01 Right thumb
02 Right index
03 Right middle
04 Right ring
05 Right little
06 Left thumb
07 Left index
08 Left middle
09 Left ring
10 Left little

The output should be written to a file with the same name as the input file but changing the extension from .raw to .sgm. For example if the input file is `image.raw` the output file should be `image.sgm`. The output file should be written in the same directory path as the input file. Examples for each image type are:

2 Inch Right Hand:

02,x_{tl},y_{tl},x_{tr},y_{tr},x_{bl},y_{bl},x_{br},y_{br}
03,x_{tl},y_{tl},x_{tr},y_{tr},x_{bl},y_{bl},x_{br},y_{br}
04,x_{tl},y_{tl},x_{tr},y_{tr},x_{bl},y_{bl},x_{br},y_{br}
05,x_{tl},y_{tl},x_{tr},y_{tr},x_{bl},y_{bl},x_{br},y_{br}
Theta

2 Inch Left Hand:

07,x_{tl},y_{tl},x_{tr},y_{tr},x_{bl},y_{bl},x_{br},y_{br}
08,x_{tl},y_{tl},x_{tr},y_{tr},x_{bl},y_{bl},x_{br},y_{br}
09,x_{tl},y_{tl},x_{tr},y_{tr},x_{bl},y_{bl},x_{br},y_{br}
10,x_{tl},y_{tl},x_{tr},y_{tr},x_{bl},y_{bl},x_{br},y_{br}
theta

3 Inch Right Hand:

02,x_{left},x_{right},y_{top},y_{bottom}
03,x_{left},x_{right},y_{top},y_{bottom}
04,x_{left},x_{right},y_{top},y_{bottom}
05,x_{left},x_{right},y_{top},y_{bottom}

3 Inch Left Hand:

07,x_{left},x_{right},y_{top},y_{bottom}
08,x_{left},x_{right},y_{top},y_{bottom}
09,x_{left},x_{right},y_{top},y_{bottom}
10,x_{left},x_{right},y_{top},y_{bottom}

3 Inch Two Thumb:

01,x_{left},x_{right},y_{top},y_{bottom}
06,x_{left},x_{right},y_{top},y_{bottom}

If the segmentation algorithm can't detect/segment one or more of the fingers it must output a -1 after the finger number indicating it could not segment that finger. For example:

02,x_{left},x_{right},y_{top},y_{bottom}
03,-1
04,x_{left},x_{right},y_{top},y_{bottom}
05,x_{left},x_{right},y_{top},y_{bottom}

4.10. Error Codes and Handling

The segmentation application shall exit with a return code of zero on success. The participant must provide documentation of all (non-zero) error or warning codes (see section 4.11).

The application should include error/exception handling so that in the case of a crash, the return code is still provided to the calling shell.

We request that the following return codes be used:

Return code	Explanation
0	Success
1	Unable to read input file
2	Unable to open input file
10	0 fingers could be segmented
11	Only 1 finger could be segmented
12	Only 2 fingers could be segmented
13	Only 3 fingers could be segmented
20 – 63	Application-specific fatal errors (explained in documentation)
64 – 127	Application-specific non-fatal warnings (explained in documentation)

All errors, warnings and informational messages shall be limited to output displayed via standard output or standard error. No GUI-type dialog windows are permitted.

4.11. Software and Documentation

4.11.1. Application type and platform

The application provided shall be command-line driven, and capable of being run in non-interactive “batch mode.” No graphical user interface (GUI) is permitted.

Test participants shall provide NIST with binaries only (i.e. no source code) for their segmentation application. Testing of segmentation systems will be performed on commercial, off-the-shelf PCs. Applications running on Red Hat Enterprise Linux 5 or Microsoft Windows Server 2003 are preferred[3]; other operating systems must be approved by the Test Liaison.

4.11.2. Installation

Segmentation software must install and run easily to be evaluated. The application shall be immediately executable without use of an installation program. Please contact the Test Liaison if an installation program is absolutely necessary. The application shall be executable on any number of machines without requiring additional machine-specific license control procedures or activation.

It is preferred that the application be packaged as a single executable file. If external libraries (such as DLLs) are necessary, they must work from the application directory, and not require installation in another location.

4.11.3. External Communication

The segmentation software running on NIST hosts shall not write any data to external resources (e.g. server, file, network connections, or other process) other than those explicitly allowed in this document.

4.11.4. Documentation

Complete documentation of application usage shall be provided, and shall detail any additional functionality or behavior beyond what is specified in this document.   The documentation must define all error and warning codes.

4.11.5. Speed

Software that runs excessively slow cannot be evaluated. On average, segmentation software should take less than five (5) seconds to segment a slap image (using a 2.8 GHZ Pentium Xeon processor). Due to resource limitations, software that takes longer than that may not be evaluated. Processing speed will be noted but will not be a primary evaluation criterion.

[3] Specific hardware and software products identified in this plan will used in order to perform the evaluations described in this document. In no case does identification of any commercial product, trade name, or vendor, imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products and equipment identified are necessarily the best available for the purpose.

4.12. Sample Data and Results

Participants must test their software using the SlapSegII sample data, and email these results to the Test Liaison for validation before sending software to NIST for evaluation

4.13. SlapSegII Calendar (Tentative)

Date	
5/8/2008	Announcement/Request for Comments
5/23/2008	End Comment Period
6/3/2008	Release Final Test Plan Start Accepting Applications
6/12/2008	Validation Data Available
6/27/2008	Last Day for Applications
8/7/2008	Validation Data Results Submission Deadline
8/13/2008	Software Submission Deadline
Oct./Nov. 2008	Results Report Issued

5. Evaluation Data

In an operational environment, slap segmentation is required for Ten-print Cards and Identification Flats. Ten-print Cards are synonymous with two inch data. Identification Flats are synonymous with three inch data. Two inch, Ten-print Card, contains a right slap and left slap without thumbs. Three inch, Identification Flats, contains a right slap, left slap, and thumbs.

The segmentation process varies for two inch data and three inch data, due to the size of the image and number of components within the image. Because of the differences in the segmentation process, the SlapSegII test will evaluate segmentation of both two inch data and three inch data as separate tests. Vendors will be given the option of selecting to participate in the two inch test, three inch test, or both. Each test will be run using data, with approximately 20,000 to 24,000 subjects per test. The two inch test will be conducted using data from the law enforcement quality data, while the three inch test will use Identification Flats from the Department of State (DOS3).

The 2 inch dataset consists of a random selection of approximately 20,000 subjects with right and left hand slap images. The data contains mostly of live-scan images and some scanned ink images. There is rotation in the images.

The three inch segmentation set will be conducted using the DOS3 dataset. The DOS3 dataset consists of a random selection of approximately 24,000 subjects with right hand, left hand, and thumb images. The thumb image is a single image that captures left and right thumb simultaneously. The data contains only live-scan images. The fingerprints are assumed vertical with no rotation so there is no rotation of the segmentation boxes.

5.1. Dataset Ground Truth

The ground truth data is based on the NIST fingerprint segmentation algorithm NFSEG. Humans examined every slap image starting with the NFSEG segmentation boxes and hand corrected all errors to produce the ground truth segmentation. The three main errors the examiners looked for were excess white space between a segmentation box edge and the fingerprint, a box side touching fingerprint ridges, and the bottom side correctly placed at the first crease. Figure 6 shows an example of ground truth segmentation boxes.

The ground truth boxes were placed to capture only the part of the finger above the first joint (ie. the finger tip). The left, right, and top sides of the segmentation boxes were placed so that a small amount of white space existed between the segmentation box and those edges of the fingerprint. Ground truth information will be included with validation data allowing users to see what is considered “small amount of white space.” If two fingers are touching the box sides are placed along the point of contact.

The bottom side of the segmentation box was placed in the middle of the first joint/crease of the finger. If there was not a well defined white space at the crease, the box was still placed in the middle of the crease cutting through any ridge information that existed. If there was a slight slant in the fingerprint, (see 2nd print in Figure 6) the bottom side was placed to include the lowest part of the crease inside the segmentation box. Ground truth segmentation boxes do not extend past the edges of the slap image for 3-inch slap images but corners could be outside the edge of the image for 2-inch data depending on rotation angle.

After initial testing results are computed some ground truth data will be reviewed as deemed necessary to detect any human errors that may exist. This will include cases where all vendors miss the segmentation or a certain number miss the segmentation box (which will depend on the number of participating vendors)

Figure 6. Sample Ground Truth Boxes.

5.2. Access to SlapSegII Test Data

The SlapSegII Test Datasets are protected under the Privacy Act (5 U.S.C. 552a), and will be treated as Sensitive but Unclassified (SBU) and/or Law Enforcement Sensitive. SlapSegII participants will not have access to SlapSegII test data, before, during, or after the test.

6. How Successful Segmentation will be Determined in SlapSegII

6.1. 3 Inch Data

The measure of a successful segmentation for the 3 inch dataset will be a comparison of the segmentation algorithm's output to hand marked ground truth coordinates to determine if they are within an acceptable tolerance. The tolerances allowed are based on matching tests done with slap image data that has rolled mates. Tolerance values were selected so that segmentation would not significantly impact a matcher's ability to match the segmented fingerprint.

A sample of slap image data was selected from a dataset that also had rolled images. Testing was conducted to determine what tolerances around the hand marked ground truth segmentation boxes would produce a minimal effect on matching results using the more accurate matchers evaluated in the proprietary fingerprint template test (PFT)[4] http://fingerprint.nist.gov/PFT/index.html.

The initial matching results were computed by matching the hand marked ground truth segmented fingerprint images against the rolled fingerprint images. A threshold was chosen based on these initial results and was fixed throughout the rest of the comparisons.

[4] Specific hardware and software products identified in this plan will used in order to perform the evaluations described in this document. In no case does identification of any commercial product, trade name, or vendor, imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products and equipment identified are necessarily the best available for the purpose.

Next each ground truth segmentation box was adjusted by various amounts and those segmentation results were matched against the same rolled images. These results were then compared to the "ground truth" results to determine how varying the edges of the ground truth box affected the number of False Rejects (FR) and False Accepts (FA) during matching.

Figure 7 shows the averages for the various matching results and different tolerances across all the fingers in both hands. The first row in the table ("Ground Truth") shows the number of false rejects and false accepts for the hand marked ground truth segmentation boxes. The "change from ground truth" columns show the difference between the number of FR/FA for a given tolerance adjustment and the ground truth value from the first row. The average number of mates in the dataset was 9,300 and the average number of non-mates was 36,713. The average size of the segmented images over the entire dataset was 270 pixels x 436 pixels.

The "All sides" rows show results for varying all four sides at the same time at the given tolerance. These two rows show that there is improvement in matcher performance when allowing the size of the segmentation boxes to increase beyond the size of the ground truth results. This allows the upper tolerance for the left, right, top and bottom to be set at +64 pixels. Since the crease is a more difficult area to detect and most of the better matchers crop the input image during enrollment, the bottom tolerance will be set to allow +128 pixels over the ground truth bottom edge.

The last 8 rows of the table show the effects of varying the left, right, top and bottom individually by -32 and -64 pixels. These results indicate a significantly larger error rate for both FR and FA when allowing a -64 pixel change to the left or right side. The top and bottom are more tolerant to a change of -64 pixels.

The 3 inch successful segmentation is then computed for each finger in the slap image as follows (gt = ground truth):

$$d_{left} = left_{gt} - left$$

$$d_{right} = right - right_{gt}$$

$$d_{top} = top_{gt} - top$$

$$d_{bottom} = bottom - bottom_{gt}$$

Successful segmentation of each finger is based on the following criteria:

$$-32 <= [d_{left}, d_{right}] <= 64$$

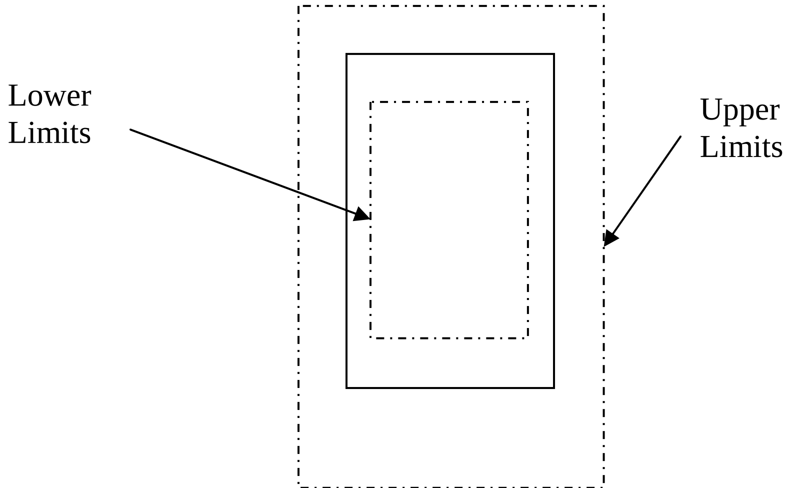
$$-64 <= d_{top} <= 64$$

$$-64 <= d_{bottom} <= 128$$

Variation	Average # False Reject	Change from Ground Truth	Average # False Accept	Change from Ground Truth
Ground Truth	77		24	
All Sides +32	68	-9	20	-4
All Sides +64	62	-15	18	-6
Left -32	86	9	34	10
Left -64	97	20	64	40
Right -32	87	10	37	13
Right -64	103	26	64	40
Top -32	78	1	25	1
Top -64	81	4	33	9
Bottom -32	80	3	27	3
Bottom -64	88	11	32	8

Figure 7. Matching results (number of FRs and FAs) for different segmentation box tolerances.

Based on the matching results shown in Figure 7 it is determined that the best tolerances for the left/right/top/bottom edges are as shown in the image and table in Figure 8. The solid line box is the size of the “average” image at 270 x 436 pixels which at 500 dpi is 0.54 inches x 0.87 inches. All the boxes are adjusted by a factor of two for better viewing.



Side	Segmentation Tolerances	
	Lower Limit (pixels)	Upper Limit (pixels)
Left/Right	-32	+64
Top	-64	+64
Bottom	-64	+128

Figure 8. 3 inch Segmentation box tolerances.

To further validate the choice of these segmentation box tolerances the NIST segmentor that was used in SlapSeg 04 was run on the data sample used to make Figure 7 and scored against the hand marked ground truth coordinates using the tolerances previously discussed and shown in Figure 8. In SlapSeg04 the NIST segmentor was able to correctly segment 3 or more "matchable" fingers an average of 94.2% for slaps across the seven datasets used in that study [1]. Using this new metric for 3 inch data, the same segmentor can segment 3 more fingers 96.0% correct.

The reported results will use the tolerance shown in Figure 8 as the desired level of performance. Other tolerances will be shown which can be useful for vendors to see where segmentation errors may be occurring. This can include (but not limited to) results given by individual edges, individual fingers, and left/right hand statistics in different finger combinations like 3 or more per hand, index/middle, index/thumb, and both index fingers

6.2. 2 Inch Data

The measure of a successful segmentation for the 2 inch dataset will also be a comparison of the segmentation algorithm's output to hand marked ground truth coordinates to determine if they are within an acceptable tolerance. The difference from the 3 inch slaps is the need to account for rotation in the segmentation boxes. The tolerances allowed are based on matching tests done with slap image data that has rolled mates. Tolerance values were selected so that segmentation would not significantly impact a matcher's ability to match the segmented fingerprint.

After trying several different methods of comparing segmentation output to ground truth for rotated data. An accurate and efficient method was to compare the four vertices ($x_{tl}, y_{tl}, x_{tr}, y_{tr}, x_{bl}, y_{bl}, x_{br}, y_{br}$) of the segmentation box to the ground truth vertices and determine if the segmentation vertices were within tolerances similar to those used with 3 inch data. The variations between the reported segmentation vertices and the ground truth are computed relative to the ground truth rotation angle as shown in Figure 9 and Figure 10 (picture on the left). The rotation angle reported by the segmentation algorithm is not used directly to determine successful segmentation but it is still being reported to assist in any error checking as needed.

The acceptable distance tolerances for the vertices were set based on the matching done for the 3 inch slap data as described in the previous section 6.1. Additional matching was performed to determine what variation in rotation to allow.

Figure 9 shows the averages for the various matching results and different rotation variations across all the fingers for both hands. The first row in the table ("Ground Truth") shows the number of false rejects and false accepts for the hand marked ground truth segmentation boxes. The "change from ground truth" columns show the difference between the number of FR/FA for a given rotation change (+/-5^o through +/- 20^o) from the ground truth rotation value. The average number of mates in the dataset was 9,300 and the average number of non-mates was 36,713. The average size of the segmented images over the entire dataset was 270 pixels x 436 pixels.

Clearly the number of false rejects increases as the rotation angle is increasingly varied from ground truth rotation. It is interesting that the number of false accepts did not increase in a similar fashion. There is no definitive increase in the number of false rejects that defines a clear tolerance point. The conservative point is to allow +/- 5^o from the ground truth angle. This coupled with the distance tolerances provides significant variation from ground truth boxes while still minimizing impact on the matcher.

Variation	Average # False Reject	Change from Ground Truth	Average # False Accept	Change from Ground Truth
Ground Truth	77		24	
Rotate 5^o	80	3	31	7
Rotate -5^o	79	2	28	4
Rotate 10^o	82	5	30	6
Rotate -10^o	82	5	29	5
Rotate 15^o	84	7	30	6
Rotate -15^o	84	7	29	5
Rotate 20^o	85	8	30	6
Rotate -20^o	87	10	29	5

Figure 9. Matching results (number of FRs and FAs) for different segmentation box rotation tolerances.

The reported segmentation vertices will be compared to the ground truth vertices relative to the ground truth angle (varied by +/-5^o). This is shown in Figure 11 in the image on the right. If the reported segmentation vertices are within tolerance at any of the three angles then it is accepted as a successful segmentation. This could mean that the top-left corner is within tolerance at $theta_{gt}+5^o$ and the bottom-right corner is within tolerance at $theta_{gt}-5^o$ and the segmentation box is still considered good.

The differences between the four vertices returned by the segmentation algorithm ($x_{tl},y_{tl},x_{tr},y_{tr},x_{bl},y_{bl},x_{br},y_{br}$) and the ground truth (gt) vertices are computed for each fingerprint in the slap image as follows (Figure 9 is a drawing of the parameter placement for the top-left corner):

$$dx1_{tl} = x_{tl} - x_{tlgt}$$

$$dx1_{tr} = x_{trgt} - x_{tr}$$

$$dx1_{bl} = x_{bl} - x_{blgt}$$

$$dx1_{br} = x_{brgt} - x_{br}$$

$$dy1_{tl} = y_{tl} - y_{tlgt}$$

$$dy1_{tr} = y_{tr} - y_{trgt}$$

$$dy1_{bl} = y_{blgt} - y_{bl}$$

$$dy1_{br} = y_{brgt} - y_{br}$$

$$d_{tl} = sqrt(((dx1_{tl})**2) + ((dy1_{tl})**2))$$
$$d_{tr} = sqrt(((dx1_{tr})**2) + ((dy1_{tr})**2))$$
$$d_{bl} = sqrt(((dx1_{bl})**2) + ((dy1_{bl})**2))$$
$$d_{br} = sqrt(((dx1_{br})**2) + ((dy1_{br})**2))$$

$$theta1_{tl} = tan^{-1}(dy1_{tl}/dx1_{tl})$$
$$theta1_{tr} = tan^{-1}(dy1_{tr}/dx1_{tr})$$
$$theta1_{bl} = tan^{-1}(dy1_{bl}/dx1_{bl})$$
$$theta1_{br} = tan^{-1}(dy1_{br}/dx1_{br})$$

$$theta_{tl} = theta1_{tl} + theta_{gt}$$
$$theta_{tr} = theta1_{tr} - theta_{gt}$$
$$theta_{bl} = theta1_{bl} - theta_{gt}$$
$$theta_{br} = theta1_{br} + theta_{gt}$$

$$dx_{tl} = int(d_{tl} * cos(theta_{tl}) + 0.5)$$
$$dy_{tl} = int(d_{tl} * sin(theta_{tl}) + 0.5)$$
$$dx_{tr} = int(d_{tr} * cos(theta_{tr}) + 0.5)$$
$$dy_{tr} = int(d_{tr} * sin(theta_{tr}) + 0.5)$$
$$dx_{bl} = int(d_{bl} * cos(theta_{bl}) + 0.5)$$
$$dy_{bl} = int(d_{bl} * sin(theta_{bl}) + 0.5)$$
$$dx_{br} = int(d_{br} * cos(theta_{br}) + 0.5)$$
$$dy_{br} = int(d_{br} * sin(theta_{br}) + 0.5)$$

These computations are repeated for $theta_{gt}-5^o$ and $theta_{gt}+5^o$ and successful segmentation is based on the difference values for any of the three angles $theta_{gt}$, $theta_{gt}-5^o$ or $theta_{gt}+5^o$ meeting the following criteria:

$$-32 <= [dx_{tl}, dx_{tr}, dx_{bl}, dx_{br}] <= 64$$
$$-64 <= [dy_{tl}, dy_{tr}] <= 64$$
$$-64 <= [dy_{bl}, dy_{br}] <= 128$$

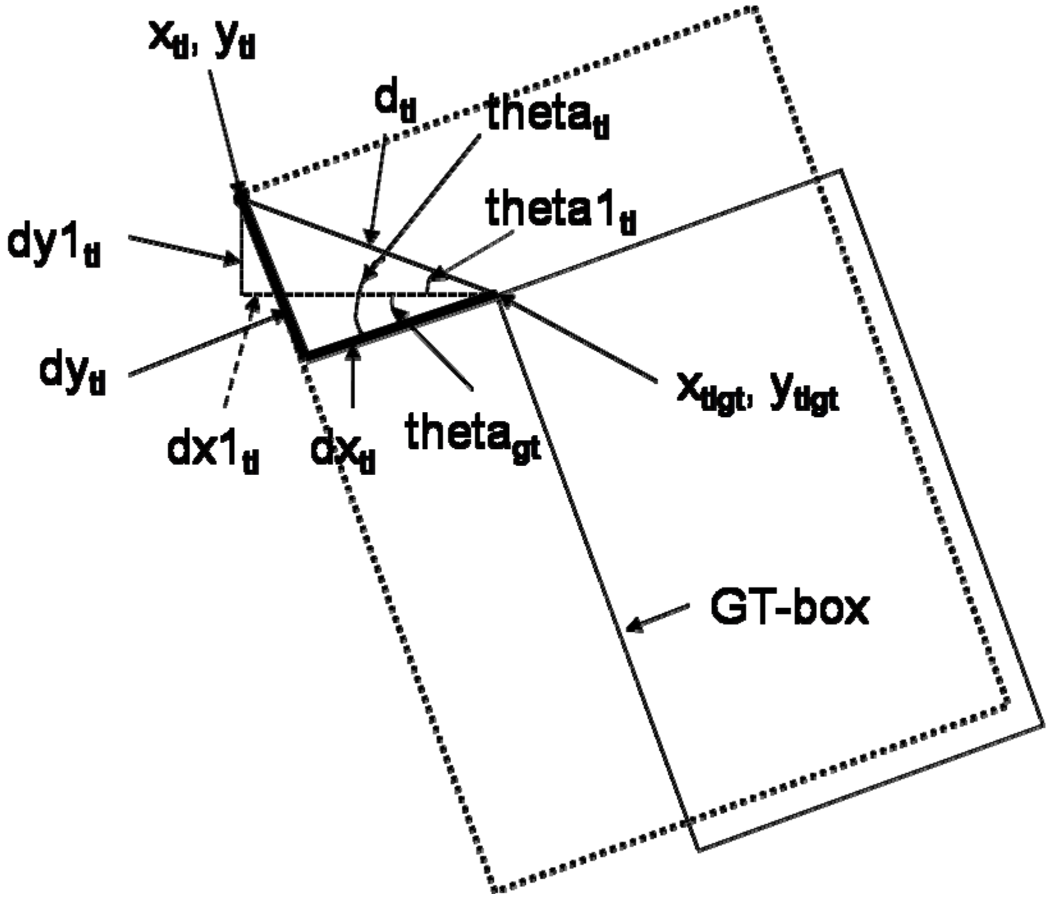
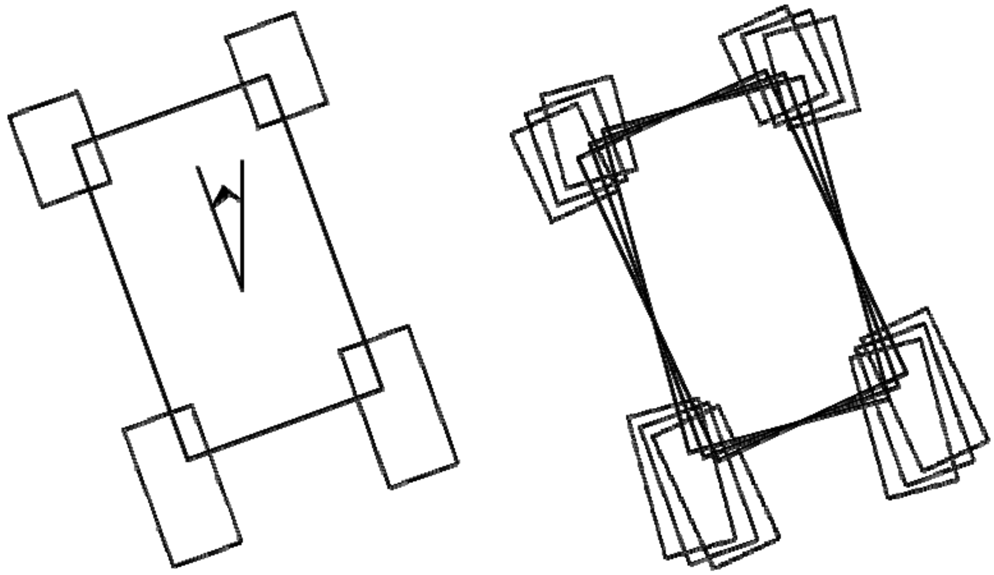


Figure 10. Shows the parameter placement (top-left corner) when computing the success measure for 2 inch segmentation boxes (this drawing is not to scale it is just intended to assist in understanding the formulas in section 6.2).

Based on the matching results shown in Figure 7 and Figure 10 it was determined that the best tolerances for the four vertices are as shown in the images and table in Figure 11. The solid line box is the size of the "average" image at 270 x 436 pixels which at 500 dpi is 0.54 inches x 0.87 inches and shown at a rotation angle of -20^o (image on the left). All the boxes are adjusted by a factor of two for better viewing. The "acceptable tolerance" box for each corner point is shown by the dotted line also rotated relative to the ground truth angle of rotation (-20^o for this example). The image on the right in Figure 10 shows the distance tolerances at +/-5^o from the ground truth angle of -20^o. Again, for successful segmentation all four vertices must be within tolerance at any of the three angular positions.



Side	Segmentation Tolerances	
	Lower Limit (pixels)	Upper Limit (pixels)
X-limits (dx)	-32	+64
Top Y-Limits (dy)	-64	+64
Bottom Y-Limits (dy)	-64	+128
Rotation	-5 degrees	+5 degrees

Figure 11. 2 inch segmentation tolerances.

To further validate the choice of these segmentation box tolerances the NIST segmentor that was used in SlapSeg 04 was run on the data sample used to make Figure 9 and scored against the hand marked ground truth coordinates using the tolerances previously discussed and shown in Figure 10. In SlapSeg04 the NIST segmentor was able to correctly segment 3 or more "matchable" fingers an average of 94.2% for slaps across the seven datasets used in that study [1]. Using this new metric for 2 inch data, the same segmentor can segment 3 more fingers 93.7% correct.

The reported results will use the tolerance shown in Figure 10 as the desired level of performance. Other tolerances will be shown which can be useful for vendors to see where segmentation errors may be occurring. This can include (but not limited to) results given by individual vertices, individual fingers, and left/right hand statistics in different finger combinations like 3 or more per hand, index/middle, index/thumb, and both index fingers

7. Conclusions

Given the advances made in technology in recent years, it is necessary to conduct an evaluation to assess current state-of-the-art slap fingerprint segmentation. By following the guidelines laid out in this document, vendors can submit SDKs for evaluation by NIST as part of SlapSegII.

By utilizing validation data, NIST will effectively minimize the potential for errors due to hardware differences prior to testing. By then conducting the evaluation using the ground truth dataset, NIST can better implement success measures to accurately determine the success of the segmentor independent of a successful match, thus providing a more accurate evaluation of the segmentation process and minimize the amount of human verification needed to check matcher errors.

8. References

1. Slap Fingerprint Segmentation Evaluation 2004 (SlapSeg04). NISTIR 7209. http://fingerprint.nist.gov/SlapSeg04

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3. "American National Standard for Information Systems – Data Format for the Interchange of Fingerprint, Facial, & Other Biometric Information – Part 1," ANSI/NIST-ITL 1-2007, NIST Special Publication 500-271, May 2007. http://fingerprint.nist.gov/standard/index.html