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IMPACT OF HUMIDITY ON LATENT PRINT PROCESSING AND RECOVERY

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A THESIS

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Table of Contents

Table of Figures

Table of Tables

Abstract

The goal of this study was to determine if environmental factors impact the quality of detail in latent prints on non-porous and porous surfaces. Specifically, this study focused on how humidity impacts latent print processing, development, and analysis on tile and paper.

Latent prints are prints deposited on surfaces in sweat (James, Nordby & Bell, 2014). As humidity is water vapor in the air, it is expected that increased humidity would have a noticeable impact on the quality of latent prints. To date, no research has been conducted comparing how humidity impacts latent prints on porous and non-porous surfaces at consistent temperatures. In this study, latent prints were deposited on a non-porous surface (white tile) and a porous surface (paper) and subjected to 30%, 50% and 90% humidity at a consistent temperature range (70-74 degrees Fahrenheit) to assess if humidity causes a noticeable change in the quality of latent prints. Once collected, prints were uploaded into the Automated Fingerprint Identification System (AFIS), which was set to automatically mark minutiae. Minutiae were then edited by an experienced latent fingerprint examiner to ensure accuracy. The edited minutiae count generated from AFIS was used to determine what category each print fell under: low quality (0-6 minutiae), moderate quality (7-12 minutiae), or high quality (13 and above minutiae). Multiple statistical tests were performed to determine statistical significance between different variables. This included comparing tracked humidities, tracked temperature ranges, overall minutiae count between humidities, and change in minutiae count over time.

Based on the results, humidity did appear to have an impact on the quality of the prints over time for both surfaces, porous and non-porous. Overall, quality decreased with increased levels of humidity. At each humidity, a decrease in quality was also observed over time. The only prints that deviated from this were the prints on the tile at 90% humidity tile. These prints

stayed at a consistent low quality. This leads to the conclusion that prints recovered on white tile with black powder and prints recovered on paper with ninhydrin decrease in quality with increased levels of humidity and also decrease over time at set humidities.

Introduction

The field of forensic science originated with the ancient Chinese, and one of the first breakthroughs was the creation of fingerprint analysis (Exploring the History, n.d.). Since this discovery, the techniques and technology used for detection and analysis have continually advanced. However, one significant area of knowledge that has not been fully explored within the literature is the effects of the environment on latent print processing and analysis.

The amount of time until a fingerprint is recovered can vary based on how long it takes to recover evidence from a crime scene or begin latent print evidence processing in a laboratory. As such, it is imperative to examine print quality over various intervals of time. The ability of different processing methods to produce quality fingerprints may change over time due to the degradation of the residue that the print is deposited in. Knowing what processes are still effective after a period of time may aid in the decision of what processing technique to use to get the highest quality print. At a crime scene, prints may be exposed to the elements. Examining how environmental factors, such as heat and humidity, impact print quality over time is important when it comes to assessing the impact of traditional recovery methods for different surfaces. While this paper reviews studies that have examined the impact of environmental factors on latent prints, many of them focus more on temperature. This study intends to add to the literature by examining the effects of humidity on the ability to recover latent prints.

Moisture is a key factor in the latent fingerprint recovery process. Latent fingerprints left on surfaces are comprised of sweat residue. The quality of a fingerprint can vary during deposition based on the amount of moisture present on the finger. Another factor that can be affected by moisture is substrate. Moisture reacts differently with non-porous surfaces versus porous surfaces. Porous surfaces will absorb the moisture, while non-porous will not. Adding additional moisture to a latent print is integral to some processing methods, such as ninhydrin. In the case of ninhydrin, the reaction that develops latent prints can be catalyzed by the addition of heat and humidity (moisture).

Considering these factors, it was hypothesized that humidity would have an impact on the ability to recover latent prints over time. This study evaluated the potential influence of humidity on latent prints on porous and non-porous surfaces. Since these surfaces react to moisture differently, it was thought that humidity would affect the quality prints of deposited on these surfaces in different ways. It was initially hypothesized that higher humidities would preserve prints deposited on porous surfaces for a longer period of time due to the continued absorption of moisture of the fingerprints on the substrate. It was also thought that prints on the non-porous substrate would be negatively affected by increased moisture as the moisture would accumulate on the surface causing distortion of the ridges. It was also thought that increased humidity would assist in the development of prints on paper processed with ninhydrin due to the fact that humidity and heat can act as a catalyst for the ninhydrin reaction. Thus it was believed that higher humidity would result in increased print quality for longer periods of time on the porous paper than on the non-porous tile. Overall, it was thought that print quality would eventually diminish at higher humidities and at longer periods of time. Research results, however, did not all align with the initial hypotheses – this is discussed in the conclusion.

Literature Review

Fingerprint Processing, Preservation, and Analysis

The scientific methodology utilized in fingerprint analysis is ACE-V methodology: analysis, comparison, evaluation, and verification (James, Nordby & Bell, 2014). In the analysis step, examiners consider the quantity and quality of detail, level 1, 2, and 3 characteristics, and anatomical source Factors influencing quality include the residue or matrix the print is deposited in, the deposition pressure, the surface or substrate the print is deposited on, environmental factors, development method, method of preservation, and the condition of the friction ridge skin. Level 1 analysis includes identifying the pattern type, such as whorl, loop or arch, the orientation, any visible scars, the number and location of cores and deltas, ridge counts and

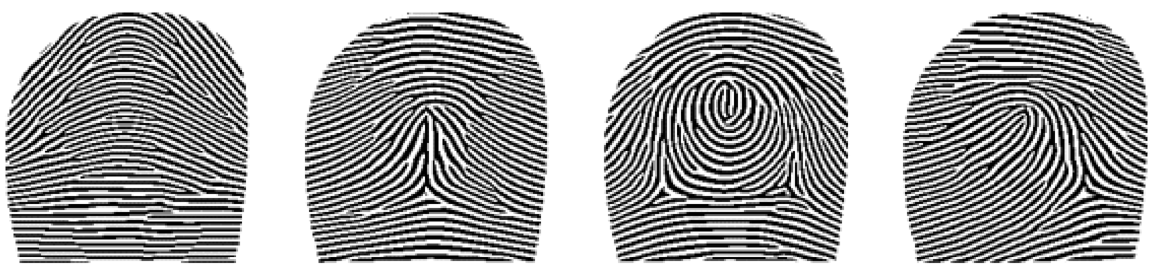


Figure 1 Examples of Fingerprint Pattern Types, (Keogh 2000).

Figure 2 Examples of Level 2 Galton Features, (Keogh, 2000)*Figure 3 Examples of Fingerprint Pattern Types,* (Keogh 2000).

whorl tracings. Examiners are unable to make an individualization during comparison of Level 1 detail, however, they are able to make an elimination. Level 2 analysis involves examining the characteristics of the ridges and labeling Galton features to include dots, bifurcations, ending ridges, and enclosures. Analysts note the direction and spatial relationship of these details in an effort to form a conclusion. An individualization or elimination can be made at this level of detail. During level 3 analysis, analysts examine the shapes, angles, and widths of ridges as well as pore locations and the spatial relationships of the pores. Identifications and eliminations can be made at this level of analysis. A fingerprint examiner will typically complete analysis of the unknown print before proceeding to the known print to reduce bias. Once a fingerprint examiner has analyzed both prints, they then move to the comparison (C) step of ACE-V which involves examining the details of the unknown and known side by side. The examiner then evaluates all the information and forms a conclusion of elimination, individualization, or inconclusive. An elimination means that a friction ridge impression cannot be identified to the individual. In an individualization, an analyst can identify a print to an individual to the exclusion of all others. An inconclusive may result from things like a lack of a known print to compare to, poor quality known prints, an insufficient amount of corresponding detail between the unknown and the known, etc. The last step of ACE-V, verification, requires another fingerprint examiner to separately perform the same ACE-V process and reach their own conclusion.

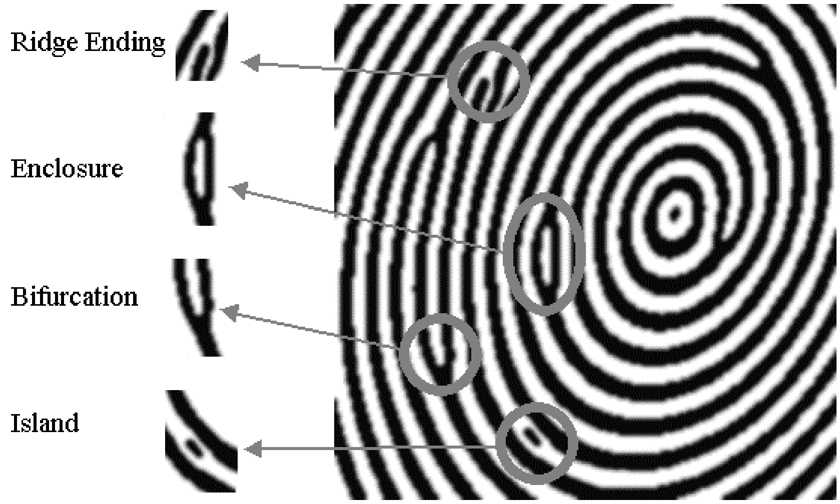


Figure 4 Examples of Level 2 Galton Features, (Keogh, 2000)

Figure 5 Halos of powder around fingerprint, (Watson, 2008).*Figure 6 Examples of Level 2 Galton Features,* (Keogh, 2000)

In order to even complete the process of ACE-V, an examiner needs fingerprint that is suitable for analysis. Suitability can be defined as having enough quality features visible withing a fingerprint to allow for comparison (Siegal, 2017). To determine this, there are certain aspects of quality that are examined: clarity, distortion, definition, and detection. Clarity is the ability to see the different levels of detail. Distortion is when the shape or form of a print is changed, usually due to how a print was deposited or outside influences like the surface type. Definition is the ability to clearly see detail, which can be based on contrasting colors or the sharpness of ridges. Lastly, detection is the ability to recognize whether a mark is a natural part of a fingerprint or an artifact. By looking at these aspects, an examiner can determine if a fingerprint has a high enough quality to allow for analysis and the formation of a conclusion.

The definition of what constitutes a quality fingerprint can vary slightly based on the examiner. This was shown during a survey of fingerprint examiners performed by Hicklin et al (2011). In this study, examiners from various laboratories were asked to examine prints and assess the local quality of different regions, the overall quality of the prints, and the pattern classification (Hicklin et al., 2011). Regarding the local quality, examiners stated what level of detail was visible in each region as well as their level of confidence when looking at each level. For overall quality, there were three conclusions to choose from: useful for identification and exclusion, useful for exclusion only, or of no use for either. If a print was labeled as "useful for identification and exclusion", the examiners were asked to rate the possible difficulty when it comes to comparison, ranging from very easy to very difficult.

The conclusions made by examiners were given a number from 0 to 6, with 0 being prints that were "of no use for identification or exclusion" and 6 being prints "useful for identification and exclusion" with a difficulty rating of "very easy" (Hicklin et al., 2011, p. 397). Lastly, for pattern classification, participants would select the pattern type for each print, selecting multiple if they were unable to definitively identify the pattern type. The results from this experiment showed “a strong relationship between the overall quality assessments and the size of local quality regions within each fingerprint” as well as “a strong relationship between accurate pattern classification and the size of local quality regions within each fingerprint” (Hicklin et al., 2011, p. 416). This study indicates that increased quality of local regions in a fingerprint is a common factor considered by examiners for determining their perception of overall print quality.

Development of Latent Fingerprints

There are three categories of fingerprints: patent, plastic, and latent. A patent fingerprint is a print that is readily visible due to the substance that the print is deposited in, such as paint or blood (James, Nordby & Bell, 2014). Plastic fingerprints are those that are formed by putting pressure into a waxy material, for example, putty. A latent print is invisible to the naked eye and must be physically or chemically enhanced to be made visible. They are made of sweat residue left behind when touching a surface. This residue is comprised of secretions from eccrine, apocrine, and sebaceous glands (Yamashita & French, 2011). Both eccrine and apocrine secretions are from sweat glands. Eccrine secretions are mostly found on the hands and feet, while apocrine comes from hair present in the armpits and pubic area. The chemical composition of eccrine secretions includes water, amino acids, and lipids, with water constituting the majority of the eccrine secretion. The amino acids within eccrine secretions are integral for the success of specific processing methods like ninhydrin. Sebaceous secretions are produced in hair as well as throughout the face and head. They mostly consist of lipids, such as fatty acids, cholesterol, and squalene. These glands are not found on the hands or feet. Sebaceous secretions can combine with eccrine secretions when areas of the body are touched.

There are also categories of surfaces where prints can be deposited, these being non-porous, porous and semi-porous. Non-porous surfaces are those that are solid and do not allow for air and moisture to move through or be absorbed (*Evidence-Processing*, n.d.). Examples include plastic, metal, and glass. Porous is the opposite; air and moisture are able to penetrate the surface. These types of surfaces include paper, cardboard, and wood. Semi-porous surfaces are those that don't necessarily belong to one of the other two categories (Yamashita & French, 2011). Based on the elements of a surface as well as the print residue, semi-porous surfaces can "both resist and absorb fingerprint residue" (Yamashita & French, 2011, p. 158). Examples include paper or cardboard covered in a film and wood covered in a finish.

The methods used to process and preserve different types of fingerprints vary based on the type of print and surface. For latent prints deposited on non-porous surfaces, powder and lifting tape are typically used for processing. Powder adheres to the moisture left behind when a latent print is deposited on a surface (James, Nordby & Bell, 2014). It is applied using a small brush, which is gently dipped into the powder and carefully dusted over the area with the latent print, with care to not over-dust or distort the print. Once visualized, a piece of clear lifting tape is applied to the print. When the lifting tape is removed from the surface, the powder sticks to the tape, transferring the friction ridge detail. The lifting tape is then adhered to a notecard with a contrasting color so that the lifted latent print can be visualized. The ingredients of latent print powders can vary depending on the type and color of surface they are intended for. For example, basic black powder is very common, but may not be the best choice when attempting to visualize a print on a dark background. In those cases, a lighter colored – or even a fluorescent – powder may be a better choice. Another method of processing with powder utilizes magnetic powder. Magnetic powder is applied using a wand in which "a magnetized steel rod can be inserted into a sheath so that, when inserted, magnetic powder can be picked up at the tip of the sheath" (Wilshire, 1996, p. 13). The powder makes up the bristles, which means the print is less likely to smear (James, Nordby & Bell, 2014). The wand can also be used to help lift any excess powder without touching the latent print, leading to a higher quality print. The adhesive used in the powder varies based on the powder, but the most “commonly used adhesives are starch, kaolin, rosin, and silica gel” (Sodhi & Kaur, 2001, p. 173).

When it comes to wet non-porous items, a commonly used method is small particle reagent (SPR). Components of SPR adhere to fatty substances generally found in sebaceous secretions (Bumbrah, 2016). The two main parts of SPR are a surfactant, which reduces the surface tension of water and enhances the moisture on surface (Bumbrah, 2016, p. 329), and a suspension material that causes the adherence of the material to the print and creates visible color. Various suspension materials are available that result in different colors. Some leave a gray color that is viewable on lighter surfaces, while others can create a white outline for darker substrates. There are even versions of SPR that use fluorescent dyes, which are useful for multi-colored surfaces. Small particle reagent can be applied by either dipping or spraying an item of evidence with potential fingerprints. The surface is then washed with distilled water. The chosen suspension material will continue to stick to the fingerprint residue, allowing for the visualization of ridge detail.

Another processing method for developing latent prints on porous surfaces is cyanoacrylate fuming. Cyanoacrylate is another name for super glue (Yamashita & French, 2011). Although super glue was originally developed in the 1950’s, it wasn’t used for latent fingerprint processing until the 1970’s when it was discovered that the fumes from the liquid substance would adhere to sweat residue. Cyanoacrylate processing can be utilized on almost all non-porous surfaces and is particularly useful for substrates that have a rough texture. To be applied to a print, cyanoacrylate must first be volatilized into a vapor. This is often done using a cyanoacrylate fuming chamber. Items of evidence are placed in the chamber and then the cyanoacrylate is heated in an aluminum dish placed inside the chamber where it turns into a vapor. The cyanoacrylate vapor and the small molecules (monomers) in the cyanoacrylate fumes bond with the latent fingerprint residue, leaving a visible polymer (a substance made up of linked monomers). This results in visible ridges that are white in color. These prints can be further enhanced after fuming using additional methods such as powders or fluorescent dye.

Fluorescence is utilized in multiple areas of forensic science other than fingerprints, including the detection of biological fluids, trace evidence, and document examination (Yamashita & French, 2011). It requires utilizing light at different energies and wavelengths to enhance the visibility of substances. Light on an object is either absorbed or reflected based on the energy of the light as well as the characteristics of the item. When visualized, the color of an object will coincide with the color of light being reflected. If there is too much energy being absorbed, the object will reflect light, this is called fluorescence. The fluoresced light will be a different color than its natural color. Fingerprint residue has its own minor innate fluorescence. However, it can be faint, so fluorescent powders or dye stains can be applied to improve clarity. Fluorescent powders are applied using the same methodology as black powder but may use a black notecard for better visualization. Dye stains are applied by spraying or dipping an item into the stain. The type of fluorescent powder or dye stain and substrate can determine what wavelength of light should be used. Once the correct light is being emitted, goggles with filters are worn, "separating the incident light generated by the light source and the weak fluorescing signal emitted by the latent print" (Yamashita & French, 2011, p. 184). The color of goggles worn (yellow, orange, or red) depends on the wavelength of the light source. To collect fingerprints enhanced using fluorescence, photographs are taken using a filter with the same color wavelength as the goggles.

Triketohydrinhene hydrate, also known as ninhydrin, is a common reagent used to develop latent fingerprints on porous surfaces (Bell et al., 2008). For fingerprint processing, ninhydrin, which is a crystalline solid, is combined with a polar solvent (Yamashita & French, 2011). Examples include water, methanol, and acetone. When applied to a latent print, this reagent reacts to the amino acids left behind in the sweat residue, creating a purple copy of the ridges. This is done by dipping or spraying the paper with ninhydrin solution. Once applied, it takes up to 24 hours for development (Bell et al., 2008). Heat and humidity can be applied to accelerate the chemical reaction, which can be done with the use of a steam iron or a ninhydrin fuming chamber. The color that appears is called Ruhemann purple, named after the person who first synthesized ninhydrin in 1910, Siegfried Ruhemann. Its application to latent fingerprint development wasn't discovered until the 1950's. Since then, analysts have worked to refine this method, eventually establishing it as a reliable and valid method of latent fingerprint processing. For this study, while it is recognized that humidity is a part of processing with ninhydrin, it is important to understand how variations in humidity impact latent print visualization on paper developed with ninhydrin.

Ninhydrin is not the only reagent that can react with the amino acids in fingerprint residue. Another reagent is 1,8-Diazafluoren-9-one (DFO), which, like ninhydrin, results in visible ridges (Yamashita & French, 2011). The reaction leaves "faint red or pink fingerprints that [are] intensely fluorescent at room temperature" (Yamashita & French, 2011, p. 18). DFO solution can be applied to a porous surface by dipping, spraying, or brushing, and then allowing the item to dry before being heated. Intense heat is necessary for the reaction to take place and can be applied using an oven or iron. Unlike ninhydrin, it is important for the DFO reaction to take place in a low-humidity environment because moisture can interfere with the reaction. For this reason, it would be counterintuitive to test this method with the proposed study. Fingerprints developed using DFO can be viewed using fluorescence. Sometimes it is recommended that DFO and ninhydrin be used consecutively to further enhance the visibility of fingerprints.

Physical developer is another reagent used for development on porous surfaces. Originally used for developing film, physical developer was discovered to be a potential fingerprint recovery method by latent print examiners in the 1970's (Bell et al., 2008). This method of enhancement is especially useful when working with porous surfaces that are wet because it reacts with molecules that don't wash away easily. Physical developer is a liquid made up of "silver ions and a reducing agent that reduces the silver ions to silver" (Bell et al., 2008, p. 199). Due to the chemical makeup of physical developer, it is applied in three steps: acid pre-treatment, physical developer treatment, and hypochlorite post-treatment. Using paper as an example, the acid pre-treatment is used to neutralize paper before adding the physical developer. Paper is then dipped into the physical developer solution where silver particles from the solution are absorbed by the fatty acids and lipids in latent fingerprint residue. The paper then undergoes a hypochlorite post-treatment that creates better contrast between the print and surface. The result leaves visible ridges that are gray or black in color.

Although not all processing methods discussed will be addressed within this study, how the quality of latent prints when developed with these methods are impacted by variations in humidity is something to consider testing in the future.

Environmental Effects on Latent Fingerprints

There are a number of factors that affect the stability of latent prints and the ability to develop them. Factors relating to human influences include the amount of sweat secreted by an individual, the chemical makeup of the print, or if an individual has rough and dry skin. Environmental factors such as heat, humidity, and light can also affect the stability and resilience of a latent print. This current study focuses on the influence that humidity has on the ability to develop quality latent prints on both porous and non-porous surfaces.

Regarding latent print quality and recovery, the impact of temperature appears to be a commonly investigated environmental factor. In one study by Colella et al. (2020), a test was conducted to determine the effect of temperature on fingerprints deposited on different areas of a lightbulb. The idea came from a case where a fingerprint from a burglary was discovered on a lightbulb. The print was matched to an individual who claimed he had touched the lightbulb many years before the burglary. At that point, there was no way to disprove the claim. This study hoped to determine if and how temperature emitted from a lightbulb affects fingerprints over time. This study also assessed if there was a way to determine age based on diminishing latent print quality.

The type of lightbulb used was a 60-watt incandescent glass bulb due to it being one of the most commonly purchased lightbulbs (Colella et al., 2020). A total of fifty lightbulbs were tested. These were separated into five groups of ten. Units composed of 2 wooden planks and socket connections for 10 lightbulbs were constructed with enough spacing between the lightbulbs to prevent them from impacting each other and skewing results. Nine lightbulbs in each group were to be turned on for a set number of hours, ranging from 18 to 672, or one month. The tenth lightbulb in all groups was off and left at room temperature to use as a control.

Colella et al. (2020) collected prints from a single donor, which were deposited on various areas of the lightbulb. Four prints were deposited on the base, four in the middle, and one on the top.

Once the set amount of time had passed, fingerprints were processed using black powder (Colella et al., 2020). Lifted prints were given a quality score from 0 to 10. It was determined that the highest temperature was from the top of the lightbulb at 156.3 degrees Celsius, with the middle of the lightbulb at 112.6 degrees Celsius, and the base at 62.7 degrees Celsius. Because this was consistent for all lightbulbs, these were designated the temperature classes. For each temperature class and the control (room temperature), the mean, range and standard deviation for quality score were calculated. An ANOVA test was run using position/temperature class, time, and rating as the variables.

The lowest mean quality score, 3.3, was from prints left on the top of the lightbulbs (Colella et al., 2020). However, not all of the prints in this temperature class were low quality. The ANOVA test showed a large amount of variability in quality scores for many of the groups in this class. Also, there were few significant differences between groups within the same class, with only four groups being statistically significant. Based on this, it was concluded that "there is no correlation between lowering of the fingerprint quality score and the amount of time the print was on the heated globe" (Colella et al., 2020, p. 94). The highest mean quality score came from the 112.6 degrees Celsius group at 5.6. This temperature class had more consistency across groups within the same class. Only two groups had a mean quality score that was statistically significant. These groups were significantly lower than others. The base groups were similar in that mean quality score was generally consistent, and only two groups had a statistically significant mean quality. Contrary to the 112.6-degree Celsius temperature class, the statistically significant groups at the base showed an increase in mean quality score. It is interesting to note that the mean quality for the control (approximately 23.1 degrees Celsius) was closest to the mean quality for the 62.7-degree Celsius class, at 4.1 and 4.5 respectively. However, the difference was not statistically significant, so it could not be said that increased temperature impacted quality. When comparing temperature classes, there were no clear trends.

Overall, the results of the study found that “potentially identifiable fingerprints can, indeed, survive exposure to high temperatures and can be used to associate people with objects/places” (Colella et al., 2020, p. 95-96). However, it is still difficult to identify a fingerprint to a specific time period and place a person at the crime scene during a particular time. Although high temperatures may not completely destroy a print, there is not a consistent pattern of detail deterioration that allows for the age of a print to be confidently determined.

While the current study will focus on the physical characteristics of fingerprints, some studies explore how environmental factors influence the chemical compounds in fingerprints. One such study by Archer et al. (2005) examined chemical changes in fingerprints over time, specifically lipids. Samples were collected from five male donors at various intervals, at least 20 minutes apart. These prints were collected throughout the day and deposited onto filter paper. Participants were required to follow a specific procedure before depositing prints. This procedure was intended to copy natural behavior as closely as possible. Participants hands were washed with alcohol and then dried before touching various areas of the face and head a specified number of times (10 times per location). Participants then rubbed their fingers together to evenly distribute substances. For each hand, the index, middle, and ring finger were sampled during each time period. Once collected, the prints were left in either light or dark conditions at consistent temperature (25 degrees Celsius) and humidity (approximately 20%). Pieces of filter paper with no fingerprints were tested to act as controls.

The initial fingerprints deposited by donors were analyzed first to determine their starting chemical composition. Four prints were then randomly selected on set days to test for chemical residues (Archer et al., 2005). The total testing period was 33 days. Samples were analyzed using gas chromatography-mass spectrometry (GC-MS). When examining the initial prints, there was variability across donors. The difference was especially notable between donors 1 and 2 and the rest of the donors as “donors 1 and 2 [deposited] only a small amount of material in their fingerprints, relative to the other donors” (Archer et al., 2005, p. 229). Donor 5 left the most residue in their initial print. Due to the large variance between donors, the authors were unable make concrete, general conclusions about how latent print chemical composition changes over time.

However, they were able to discern trends for certain substances (Archer et al., 2005). For example, squalene, a lipid found in the natural oils produced by skin, appeared to decrease at a rapid rate when exposed to light. Although, squalene did degrade in samples left in the dark, the loss was not as quick. The same trends were observed with cholesterol. Conclusions were also made regarding fatty acids. Short-chain fatty acids, such as hexanoic, octanoic and nonanoic, increased with time. Levels of long-chain fatty acids were more consistent throughout the study and there were no observable increases for these substances over time. Fingerprints in both lighting conditions showed a similar trend with saturated fatty acids. These acids would increase in the beginning before decreasing to measurements consistent with the initial print or at values lower than this measurement. The two unsaturated fatty acids that were tracked, palmitoleic and oleic, had different trends depending on light exposure. In the dark, both substances followed the same trend as saturated fatty acids: increasing early on before decreasing to the original or lower level. Palmitoleic acid continued this pattern in the light. Levels of oleic acid, however, were not consistent under the light condition. In some prints, oleic acid would increase then decrease, while in others it would only decrease.

A study conducted by Alcaraz-Fossoul et al. (2013) used a real-life scenario to determine the age of a print deposited on a plastic container inside a slot machine. In this case, a burglary had occurred and money was taken from a slot machine. A fingerprint was found on the container that held the coins. The individual who the fingerprint was identified to worked for the slot machine company; however, the individual stated that his fingerprint was deposited on the container when he collected the coins 6 months before the burglary. The researchers behind the study wanted to see if they could replicate the environmental conditions as closely as possible and test if the degradation patterns of the print were similar to that found on the container. When performing the study, the researchers tested eccrine secretions, which are naturally from fingers, and sebaceous secretions, which come from touching other parts of the body. They used two types of surfaces, glass and polystyrene. There were 11 collection days that started on the day of deposition and ended after 6 months. For each collection day, there were "18 impressions on polystyrene (nine each, eccrine and sebaceous) and 12 impressions on glass (six each, eccrine and sebaceous)" (Alcaraz-Fossoul et al., 2013, p. 860). Prints were exposed to different light exposures identified as light, medium, and dark. The researchers tracked a large variety of factors, which were separated into groups: variable, fixed, and constant. Temperature, relative humidity, and light exposure were considered variable factors; surface type, secretion type, and exposure type were fixed factors; and donor and the amount of pressure applied were constant factors.

Alcaraz-Fossoul et al.'s (2013) study indicated that on glass surfaces, light exposure did not cause any major differences over time for both types of secretions. For sebaceous samples, fingerprints at all light exposure levels showed similar amounts of degradation. The only difference noticed was that powder appeared to adhere slightly better in the dark, but, overall, prints had similar visibility. For eccrine samples on glass, there was little difference in print quality for the light and dark conditions. It was noted that fingerprints in the dark condition appeared to degrade at a faster rate than fingerprints in the light condition (Alcaraz-Fossoul et al., 2013, p. 866). When comparing eccrine samples to sebaceous samples, the minutiae count for eccrine samples were generally lower than sebaceous samples in both lighting conditions.

For polystyrene substrates, lighting conditions had a noticeable impact on sebaceous prints. This was seen in halos of powder reagent that started appearing after the first week (Alcaraz-Fossoul et al., 2013). These halos were especially visible in dark conditions and became more prominent over time. Prints exposed to a lighter environment also displayed halos, but they were less pronounced than those from the dark exposure. Light exposure also caused ridges to become thinner. While all the fingerprints decreased in quality over time, the change was more prominent on polystyrene than glass. When examining eccrine latent fingerprints for both surfaces, as time went on, ridges became thinner. The only main difference was that there was no visible halo on the polystyrene for eccrine latent fingerprints compared to sebaceous prints. The authors believe that the halos came from “grease

Figure 7 Halos of powder around fingerprint, (Watson, 2008).

diffusion" (Alcaraz-Fossoul et al., 2013, p. 864), which would most likely not be present for eccrine fingerprints.

When reviewing the environmental factors, sebaceous latent prints on glass did not show any major visual differences caused by any of the environmental factors (Alcaraz-Fossoul et al., 2013). A factor that stood out was the discovery that "solar radiation appeared to fix or desiccate samples on glass" (Alcaraz-Fossoul et al., 2013, p. 866). For polystyrene, it was found that "more constant climate values improved preservation and subsequent visualization of samples" and that insulation was "the least influencing of factors for the durability of latent fingerprints" (Alcaraz-Fossoul et al., 2013, p. 866). Eccrine latent prints on glass also showed better powder development with higher solar radiation. Unlike sebaceous prints, on glass, more constant climate actually decreased the quality of the eccrine latent prints. Maintaining a constant climate also did not help the eccrine prints on the polystyrene surfaces. Overall, it was found that for both sebaceous and eccrine prints environmental conditions have less of an impact on prints deposited on glass surfaces versus those on plastic surfaces.

Other studies have explored the impact of heat and humidity on the enhancement of fingerprints (Cadd et al., 2015). Some examples include the use of ninhydrin, DFO, physical developer, and cyanoacrylate fuming. A study by Dominick et al. (2009) examined the effect of high temperature on recovering latent prints from unopened recycled white paper using different recovery methods. The goal was to determine if prints exposed to extremely high temperatures, like those found in cases of arson, were still recoverable. Five donors with unwashed hands deposited prints on a depletion grid written on pieces of paper. Before being deposited, participants rubbed their fingers together to ensure that residue was distributed evenly.

Before being exposed to the various temperatures, prints were left to sit in normal environmental conditions for 1 hour to 1 month to allow for natural aging (Dominick et al., 2009). All prints were then subjected to different temperatures at various exposure times. Temperatures ranged from 50 degrees Celsius to 200 degrees Celsius, while exposure time was between 10 and 320 minutes. Higher temperatures were created using an oven.

For all processing methods, a scoring system was developed ranging from 0 to 4, with 0 being no visible detail and 4 being completely visible ridges (Dominick et al., 2009). Once scored, an ANOVA (Analysis of Variance) test was run to find the statistical significance of the three controlled factors: age, temperature, and exposure time. Prints were originally going to be processed using only ninhydrin, 1,8-diazafluoren-9-one (DFO), and physical developer (PD), however, the authors ultimately added fluorescence as an enhancement method. This entailed viewing the prints with "the green light waveband of a Quaser 2000 (473 to 548 nm) using a 549 nm viewing filter" (Dominick et al., 2009, p. 329). Note, only the fingerprints exposed to 150 degrees Celsius naturally fluoresced. ANOVA test results for fluorescence showed that temperature and exposure time had a statistically significant effect on the fingerprint scores. While age by itself did not have a significant effect, the impact was significant when paired with temperature.

Visually, ninhydrin did not appear to be very effective at higher temperatures (Dominick et al., 2009). It was determined that this was because of color contrast. At higher temperatures, the paper began to turn brown, so the purple color that develops from ninhydrin was not as visible. Statistics from the ANOVA test showed "that all three variables, and their subsequent interactions (except for the three-way interaction) [had] a significant effect to the resulting fingerprint score" (Dominick et al., 2009, p. 332).

Fingerprints enhanced with DFO were viewed using the same conditions as those enhanced with only fluorescence (Dominick et al., 2009). As the temperature increased, the prints began to fluoresce as well as the background. At the highest temperatures, 150 degrees Celsius and 200 degrees Celsius, prints no longer fluoresced. For DFO, all factors and interactions showed statistical significance when performing an ANOVA test. While both ninhydrin and DFO became less effective at higher temperatures, based on the ANOVA results, it appeared that DFO was more effective than ninhydrin.

In arson cases, which was the motivation behind conducting this experiment, it may be necessary for firefighters to use water to put out a fire (Dominick et al., 2009). In scenarios where paper is wet, physical developer is a common method that can be effective. Because of this, it was necessary to examine if conditions before paper becomes wet, like the intense heat of a fire, impacts the ability to recover prints using physical developer. Ratings for physical developer-enhanced prints did not show any clear trends. However, ANOVA scores did indicate that all factors and interactions had statistical significance.

The final ANOVA test evaluated the fourth factor: recovery technique (Dominick et al., 2009). Results showed that all four variables and a majority of interactions were statistically significant. The only pairings that did not show statistical significance were temperature with age and temperature, age and exposure time. This ANOVA test included another feature called interaction plots, which “showed the impact that changing the settings of one factor has on another factor by comparing the mean responses” (Dominick et al., 2009, p. 336). The interaction plots showed that DFO was the most effective recovery method, followed by physical developer then ninhydrin. Note that while this study found DFO and physical developer were generally more effective for recovering prints from paper, for the current study, it was still decided to use ninhydrin as it is the most commonly used method in crime labs for processing prints on porous surfaces. Ninhydrin is also quick and does not call for an oven or heat gun. As for the other factors (temperature, exposure time and age), while each had some impact on the quality of the prints, interaction plots indicated that the most impactful was temperature. Overall, this study found "that fingerprints [were] still retrievable from paper that [had] been subjected to the maximum testing conditions of 200ºC for 320 minutes" (Dominick et al., 2009, p. 325).

A study conducted by Paine et al. (2011) examined how humidity impacts cyanoacrylate fuming. The goal of this study was to examine how relative humidity affects the overall quality of a print recovered using cyanoacrylate. To test the effect on overall quality, three types of prints were deposited on plastic sheets. These were defined as natural, groomed eccrine, and groomed sebaceous. Natural prints were collected from participants who had not washed their hands. Those providing groomed eccrine prints were required to wash their hands with soap, water, and ethanol. Once fully dried, donors wore latex gloves for 30 minutes to protect the print when touching other surfaces. Groomed sebaceous prints were collected from donors following the same washing procedure as the groomed eccrine prints. However, after completely drying their hands, these participants rubbed areas of the face before immediately depositing fingerprints.

Each donor used one finger to lay 9 continuous prints in a grid marked on the sheets of plastic (Paine et al., 2011). It was assumed that each print laid would degrade in quality due to less residue remaining. The authors reasoned that this may determine "the sensitivity of a technique according to how far down the depletion series marks continue to be developed" (Paine et al., 2011, p. 132). After being deposited, the plastic sheets were kept at room temperature for one week before being subjected to three tests, with prints from 16 participants in each test. These tests included examining the groomed sebaceous prints at 80% relative humidity, the groomed eccrine prints at 80% relative humidity, and the natural prints at 60%, 70%, 80%, 90% and 100% relative humidity. Parameters were chosen due to prior literature, which stated that "the optimum relative humidity for development was approximately 80%" (Paine et al., 2011, p. 131).

A scoring system was developed to rate the general quality of processed prints (Paine et al., 2011). It ranged from 0 to 4, with 0 being no visible detail and 4 being completely clear ridge detail. Once graded, the average and standard deviation was calculated for each relative humidity. The results acquired from the natural marks supported results from previous literature; the average score increased until reaching 80% humidity before decreasing at higher humidities corroborating 80% humidity being the optimal condition. Visually, cyanoacrylate appeared to adhere to fingerprint residue less for lower humidities and increased as humidity intensified. The groomed eccrine marks showed a similar trend in that average quality score increased at higher relative humidities before decreasing. However, the quality continued to increase up to 90% relative humidity before sharply degrading at 100% humidity. As with the natural fingerprints, the optimal relative humidity was around 80%. For groomed sebaceous prints, there did not "seem to be an obvious relationship between humidity and mark quality" (Paine et al., 2011, p. 138). Due to humidity being an important part of processing with ninhydrin, as with cyanoacrylate fuming, it is suspected that the current study could see similar results.

Methodology

This study focused on the effects of humidity on the processing, recovery, and quality of latent print impressions on porous and non-porous surfaces. White tiles were used as the non-porous surface while white computer paper was used for the porous surface. Forty-five prints were deposited on white tiles and forty-five prints were deposited on white paper for each humidity setting. Prints on the tiles were processed using black powder and prints on the paper were processed using ninhydrin. Testing took place over several months (approximately 3 months) with the amount of time between development going from smaller to larger time intervals. Prints were processed on days 1, 3, 5, and 7, then once a week until reaching 15 lifts total. It was decided that three prints would be processed for each designated day instead of just one print to ensure that the results of the recovery were accurate and not due to an error during the development process. All prints were from the same person using the same finger (right index). A sebaceous oil pad was used to help maintain consistency in the amount of residue each print was deposited in. Each print was deposited with the same amount of pressure for the same amount time.

The experiment assessed latent print quality at three different humidities. The temperature was kept at a steady range, between 70 to 74 degrees Fahrenheit. Group 1 was kept between approximately 20% to 40% humidity, Group 2 was between 45% to 60% humidity, and Group 3 was 85% to 100% humidity. These conditions were created and controlled using ninhydrin fuming chambers and a humidifier. Black powder was used to process the white tile prints using a fiberglass brush. Pictures were taken of the powdered prints on the tile. Prints from the paper were sprayed with ninhydrin then developed using heat from an iron. As with the tile prints, these prints were photographed. All photographs of latent prints were analyzed by the primary investigator. The primary investigator also examined the actual paper with the ninhydrin prints (in addition to the photographs) after a period of time to make sure that better development did not occur over time. Prints were then uploaded to the Automatic Fingerprint Identification System (AFIS) by a qualified latent fingerprint examiner. Those that were deemed as having no visibility by the primary examiner were not sent to the latent fingerprint examiner for uploading to AFIS. Once the prints were uploaded into AFIS, the system was set to automatically map minutiae and produce an overall minutiae count. Due to the possibility of AFIS incorrectly marking potential minutiae, the qualified latent fingerprint examiner reviewed and edited the marks that were not true minutiae. The cleaned-up minutiae count from AFIS determined the level of quality for each print. Fingerprints with a minutiae count between 0-6 were considered low quality, 7-12 were moderate quality, and 13 or more were high quality. The level of quality of the prints were compared within humidity groups as well as with prints from the other groups to see if there were any noticeable trends.

Various statistical tests were run to determine statistical significance. Standard descriptive statistics, including mean and standard deviation were used to characterize the data. Changes in quality of fingerprints over time, as determined by number of AFIS minutiae, were assessed by linear regression analysis. Comparisons of overall number of AFIS minutiae between conditions was conducted using an unpaired t-test assuming parametric distributions. Lastly, comparisons between more than one group were conducted using an ANOVA, Analysis of Variance, test.

Results

Thirty-Percent Humidity

The majority of the prints developed on the non-porous surface (white tile) that had been exposed to 30% humidity were considered high quality. In fact, 39 of the 43 high quality prints had over 20 visible minutiae. There were two prints from the non-porous surface at 30% humidity that had moderate quality (prints 9A and 15C), but they were at the higher end of the moderate range with 10 and 12 marked minutiae. These two prints were processed in the later stages of the experiment. For the porous surface (paper), the quality of the prints at 30% humidity was markedly lower than the quality of the prints on the porous surface at the same humidity. The first group of prints developed on paper exhibited very high quality, with over 30 visible minutiae, before a sudden decrease in quality for print groups 2 and 3, dropping to around 5 or 6 minutiae or even no visible minutiae. The prints in groups 2 and 3 were all considered low quality. After print 3A, prints on the paper at 30% humidity were either not visible or those that were visible had only a very few minutiae marked and were low quality. There was one unexpected outlier close to the end of the experiment that had high quality, 13A, which showed 18 minutiae. However, the other two in the set, 13B and 13C, had no visible ridge detail, so this sudden change may have been caused by some other factor.

30% Black Powder - Tile

#	Letter	Date	Temp. Range (°F)	Humidity Range (%)	Ridges Present	AFIS Seach #	AFIS Minutiae Count		Quality
							Before Clean-up	After Clean-up	
1	A	12/7/2022	70.9-71.2	37.2-39.4	Y	TUL2023000419/001	28	29	High
	B				Y	TUL2023000419/002	39	40	High
	C				Y	TUL2023000419/003	269	32	High
2	A	12/9/2022	71.2-72.5	36.4-39.0	Y	TUL2023000419/004	47	44	High
	B				Y	TUL2023000419/005	28	26	High
	C				Y	TUL2023000419/006	46	41	High
3	A	12/11/2022	71.0-71.7	36.0-40.2	Y	TUL2023000419/007	33	24	High
	B				Y	TUL2023000419/008	27	25	High
	C				Y	TUL2023000419/009	29	32	High
4	A	12/13/2022	72.4-73.1	36.5-37.2	Y	TUL2023000419/010	46	41	High
	B				Y	TUL2023000419/011	41	31	High
	C				Y	TUL2023000419/012	48	35	High
5	A	12/20/2022	71.2-71.5	33.5-34.0	Y	TUL2023000419/013	54	37	High
	B				Y	TUL2023000419/014	22	20	High
	C				Y	TUL2023000419/015	38	28	High
6	A	12/27/2022	72.3-72.7	39.1-41.4	Y	TUL2023000421/001	32	29	High
	B				Y	TUL2023000421/002	21	20	High
	C				Y	TUL2023000421/003	44	40	High
7	A	1/3/2023	71.5-71.9	37.3-38.1	Y	TUL2023000421/004	48	32	High
	B				Y	TUL2023000421/005	39	16	High
	C				Y	TUL2023000421/006	38	22	High
8	A	1/10/2023	72.2-72.5	34.7-35.1	Y	TUL2023000421/007	24	15	High
	B				Y	TUL2023000421/008	39	33	High
	C				Y	TUL2023000421/009	38	21	High
9	A	1/17/2023	71.7-72.2	19.1-24.3	Y	TUL2023000421/010	18	10	Moderate
	B				Y	TUL2023000421/011	40	32	High
	C				Y	TUL2023000421/012	38	27	High
10	A	1/24/2023	71.3-72.0	25.2-29.6	Y	TUL2023000421/013	33	27	High
	B				Y	TUL2023000421/014	27	21	High
	C				Y	TUL2023000421/015	28	20	High
11	A	1/31/2023	70.9-71.4	27.2-31.0	Y	TUL2023000421/016	31	30	High
	B				Y	TUL2023000421/017	38	30	High
	C				Y	TUL2023000421/018	35	30	High
12	A	2/7/2023	71.4-71.7	21.3-22.9	Y	TUL2023000421/019	34	25	High
	B				Y	TUL2023000421/020	32	29	High
	C				Y	TUL2023000421/021	34	26	High
13	A	2/14/2023	72.1-72.7	22.4-23.7	Y	TUL2023000421/022	40	30	High
	B				Y	TUL2023000421/023	26	19	High
	C				Y	TUL2023000421/024	43	36	High
14	A	2/21/2023	71.4-72.1	23.6-24.1	Y	TUL2023000421/025	36	25	High
	B				Y	TUL2023000421/026	26	26	High
	C				Y	TUL2023000421/027	33	29	High
15	A	2/28/2023	71.5-71.7	21.8-22.9	Y	TUL2023000421/028	28	15	High
	B				Y	TUL2023000421/029	40	35	High
	C				Y	TUL2023000421/030	23	12	Moderate

Table 1 30% Humidity Tile Results

30% Ninhydrin - Paper

#	Letter	Date	Temp. Range (°F)	Humidity Range (%)	Ridges Present	AFIS Seach #	AFIS Minutiae Count		Quality
							Before Clean-up	After Clean-up	
1	A	12/7/2022	70.9-71.2	37.2-39.4	Y	TUL2023000418/001	35	32	High
	B				Y	TUL2023000418/002	28	33	High
	C				N	-	-	-	Low
2	A	12/9/2022	71.2-72.5	36.4-39.0	Y	TUL2023000418/003	38	6	Low
	B				Y	TUL2023000418/004	35	6	Low
	C				Y	TUL2023000418/005	26	6	Low
3	A	12/11/2022	71.0-71.7	36.0-40.2	Y	TUL2023000418/006	36	5	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
4	A	12/13/2022	72.4-73.1	36.5-37.2	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
5	A	12/20/2022	71.2-71.5	33.5-34.0	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
6	A	12/27/2022	72.3-72.7	39.1-41.4	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
7	A	1/3/2023	71.5-71.9	37.3-38.1	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
8	A	1/10/2023	72.2-72.5	34.7-35.1	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
9	A	1/17/2023	71.7-72.2	19.1-24.3	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
10	A	1/24/2023	71.3-72.0	25.2-29.6	Y	TUL2023000418/007	12	4	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
11	A	1/31/2023	70.9-71.4	27.2-31.0	Y	TUL2023000418/008	16	4	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
12	A	2/7/2023	71.4-71.7	21.3-22.9	Y	TUL2023000418/009	10	3	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
13	A	2/14/2023	72.1-72.7	22.4-23.7	Y	TUL2023000418/010	39	18	High
	B				N	-	-	-	Low
	C				N	-	-	-	Low
14	A	2/21/2023	71.4-72.1	23.6-24.1	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
15	A	2/28/2023	71.5-71.7	21.8-22.9	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low

Table 2 30% Humidity Paper Results

Fifty-Percent Humidity

The prints deposited on the non-porous (white tile) surface at 50% humidity generally had high quality. However, the quality was not as consistently high as what was observed for prints on the non-porous surface at 30% humidity. Thirty-three prints were of high quality. However, only 15 of the 33 prints had 20 or more minutiae marked. The moderate prints that were observed on the non-porous surface at 50% humidity were in the last three to four print groups. There were also a few low-quality prints observed, specifically prints 1C and 15C with 6 minutiae observed in both prints. The low quality of print 1C may have been due to an extraneous factor like a processing error as it was one of the first prints developed. The prints deposited on the porous surface (paper) at 50% humidity generally showed a lower quality than the prints from the tiles at 50% humidity and had a more drastic decrease in quality over time. The prints started with mostly high and moderate quality, with a minimum of 8 and maximum of 16 minutiae, before becoming consistently low around print group 7. When the prints first became lower quality, there were still marked minutiae, usually between 2 and 6 minutiae points. After print group 7, there no longer appeared to be visible minutiae, other than 9A which had 1 marked minutia. When comparing the prints on paper at 50% humidity to the prints on paper at 30% humidity, the prints at 50% humidity appeared to have maintained quality for a longer period of time than the prints deposited at 30% humidity.

50% Black Powder - Tile									
#	Letter	Date	Temp. Range (°F)	Humidity Range (%)	Ridges Present	AFIS Seach #	AFIS Minutiae Count		Quality
							Before Clean-up	After Clean-up	
1	A	8/30/2022	71.7-73.3	57.1-57.5	Y	TUL2023000501/001	44	27	High
	B				Y	TUL2023000501/002	19	7	Moderate
	C				Y	TUL2023000501/003	15	6	Low
2	A	9/1/2022	71.3-72.6	58.1-58.6	Y	TUL2023000501/004	26	14	High
	B				Y	TUL2023000501/005	45	34	High
	C				Y	TUL2023000501/006	38	16	High
3	A	9/3/2022	71.2-71.4	56.7-57.2	Y	TUL2023000501/007	31	20	High
	B				Y	TUL2023000501/008	23	20	High
	C				Y	TUL2023000501/009	35	25	High
4	A	9/5/2022	71.4-71.8	58.2-59.0	Y	TUL2023000501/010	38	29	High
	B				Y	TUL2023000501/011	19	14	High
	C				Y	TUL2023000501/012	27	22	High
5	A	9/13/2022	71.1-73.8	55.6-56.7	Y	TUL2023000501/013	25	14	High
	B				Y	TUL2023000501/014	32	36	High
	C				Y	TUL2023000501/015	14	12	Moderate
6	A	9/20/2022	70.9-72.8	56.0-56.6	Y	TUL2023000509/001	35	26	High
	B				Y	TUL2023000509/002	39	19	High
	C				Y	TUL2023000509/003	23	12	Moderate
7	A	9/27/2022	71.5-73.73	52.0-52.5	Y	TUL2023000509/004	39	29	High
	B				Y	TUL2023000509/005	31	18	High
	C				Y	TUL2023000509/006	28	22	High
8	A	10/4/2022	70.9-72.5	45.0-45.4	Y	TUL2023000509/007	33	27	High
	B				Y	TUL2023000509/008	23	16	High
	C				Y	TUL2023000509/009	17	14	High
9	A	10/11/2022	71.1-72.1	45.0-45.2	Y	TUL2023000509/010	44	27	High
	B				Y	TUL2023000509/011	26	16	High
	C				Y	TUL2023000509/012	18	12	Moderate
10	A	10/18/2022	71.7-73.0	47.5-54.0	Y	TUL2023000509/013	29	22	High
	B				Y	TUL2023000509/014	21	17	High
	C				Y	TUL2023000509/015	26	21	High
11	A	10/25/2022	71.1-71.5	58.7-58.8	Y	TUL2023000509/016	21	13	High
	B				Y	TUL2023000509/017	12	12	Moderate
	C				Y	TUL2023000509/018	23	15	High
12	A	11/1/2022	71.1-71.5	49.0-51.5	Y	TUL2023000509/019	23	19	High
	B				Y	TUL2023000509/020	16	18	High
	C				Y	TUL2023000509/021	16	10	Moderate
13	A	11/8/2022	71.5-71.7	52.3-52.4	Y	TUL2023000509/022	22	8	Moderate
	B				Y	TUL2023000509/023	23	15	High
	C				Y	TUL2023000509/024	20	16	High
14	A	11/15/2022	71.2-71.7	53.4-54.1	Y	TUL2023000509/025	22	7	Moderate
	B				Y	TUL2023000509/026	28	16	High
	C				Y	TUL2023000509/027	31	11	Moderate
15	A	11/22/2022	70.9-71.4	55.2-56.1	Y	TUL2023000509/028	22	14	High
	B				Y	TUL2023000509/029	21	11	Moderate
	C				Y	TUL2023000509/030	20	6	Low

Table 3 50% Humidity Tile Results

50% Ninhydrin - Paper									
#	Letter	Date	Temp. Range (°F)	Humidity Range (%)	Ridges Present	AFIS Seach #	AFIS Minutiae Count		Quality
							Before Clean-up	After Clean-up	
1	A	8/30/2022	71.7-73.3	57.1-57.5	Y	TUL2023000425/001	36	16	High
	B				Y	TUL2023000425/002	39	15	High
	C				Y	TUL2023000425/003	52	8	Moderate
2	A	9/1/2022	71.3-72.6	58.1-58.6	Y	TUL2023000425/004	28	5	Low
	B				Y	TUL2023000425/005	20	9	Moderate
	C				Y	TUL2023000425/006	12	6	Low
3	A	9/3/2022	71.2-71.4	56.7-57.2	Y	TUL2023000425/007	24	11	Moderate
	B				Y	TUL2023000425/008	11	3	Low
	C				Y	TUL2023000425/009	26	2	Low
4	A	9/5/2022	71.4-71.8	58.2-59.0	Y	TUL2023000425/010	24	2	Low
	B				Y	TUL2023000425/011	19	2	Low
	C				Y	TUL2023000425/012	21	3	Low
5	A	9/13/2022	71.1-73.8	55.6-56.7	Y	TUL2023000425/013	21	3	Low
	B				Y	TUL2023000425/014	18	2	Low
	C				Y	TUL2023000425/015	15	2	Low
6	A	9/20/2022	70.9-72.8	56.0-56.6	Y	TUL2023000425/016	24	9	Moderate
	B				Y	TUL2023000425/017	22	4	Low
	C				Y	TUL2023000425/018	39	5	Low
7	A	9/27/2022	71.5-73.73	52.0-52.5	Y	TUL2023000425/019	17	2	Low
	B				Y	TUL2023000425/020	37	2	Low
	C				Y	TUL2023000425/021	13	2	Low
8	A	10/4/2022	70.9-72.5	45.0-45.4	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
9	A	10/11/2022	71.1-72.1	45.0-45.2	Y	TUL2023000425/022	10	1	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
10	A	10/18/2022	71.7-73.0	47.5-54.0	Y	TUL2023000425/023	28	0	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
11	A	10/25/2022	71.1-71.5	58.7-58.8	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
12	A	11/1/2022	71.1-71.5	49.0-51.5	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
13	A	11/8/2022	71.5-71.7	52.3-52.4	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
14	A	11/15/2022	71.2-71.7	53.4-54.1	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
15	A	11/22/2022	70.9-71.4	55.2-56.1	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low

Table 4 50% Humidity Paper Results

Ninety-Percent Humidity

The prints deposited on the non-porous surface (white tile) at 90% humidity had the most drastic change in quality. The prints displayed large variation in the number of visible minutiae. A majority of the prints (18 prints) were of low quality. Most of the low-quality prints were observed in the last few groups of developed prints. The majority of the high-quality prints, which totaled 14, were in the middle groups, specifically print groups 8 through 12. Those that were high quality were on the lower end of the high-quality range, between 13 to 19 points, and only five having 20 or more minutiae. Moderate prints were observed consistently throughout the beginning and middle groups. This differed from the prints on white tile at both 30% and 50% humidity which were consistently high quality throughout all of these groups. None of the prints on paper at 90% humidity had any visible ridges or countable minutiae indicating 90% humidity had a huge impact on the development of prints on the paper.

90% Black Powder - Tile									
#	Letter	Date	Temp. Range (°F)	Humidity Range (%)	Ridges Present	AFIS Seach #	AFIS Minutiae Count		Quality
							Before Clean-up	After Clean-up	
1	A	8/30/2022	71.5-72.8	98.6-98.9	Y	TUL2023000522/001	28	8	Moderate
	B				Y	TUL2023000522/002	16	13	High
	C				Y	TUL2023000522/003	18	9	Moderate
2	A	9/1/2022	71.1-72.1	99.2-99.5	Y	TUL2023000522/004	28	24	High
	B				Y	TUL2023000522/005	11	6	Low
	C				N	-	-	-	Low
3	A	9/3/2022	71.1-72.3	98.7-99.0	Y	TUL2023000522/006	38	10	Moderate
	B				Y	TUL2023000522/007	16	9	Moderate
	C				Y	TUL2023000522/008	38	5	Low
4	A	9/5/2022	70.8-72.1	98.0-99.9	Y	TUL2023000522/009	21	8	Moderate
	B				Y	TUL2023000522/010	26	5	Low
	C				Y	TUL2023000522/011	19	10	Moderate
5	A	9/13/2022	70.9-73.2	99.0-99.1	Y	TUL2023000522/012	12	6	Low
	B				Y	TUL2023000522/013	35	17	High
	C				Y	TUL2023000522/014	20	6	Low
6	A	9/20/2023	70.8-72.7	96.9-98.1	Y	TUL2023000601/001	30	7	Moderate
	B				Y	TUL2023000601/002	21	8	Moderate
	C				Y	TUL2023000601/003	11	5	Low
7	A	9/27/2022	71.3-72.2	92.1-99.0	Y	TUL2023000601/004	11	6	Low
	B				Y	TUL2023000601/005	9	2	Low
	C				Y	TUL2023000601/006	11	11	Moderate
8	A	10/4/2022	70.8-71.4	91.3-93.0	Y	TUL2023000601/007	10	2	Low
	B				Y	TUL2023000601/008	15	9	Moderate
	C				Y	TUL2023000601/009	23	16	High
9	A	10/11/2022	70.9-71.7	84.0-91.0	Y	TUL2023000601/010	21	16	High
	B				Y	TUL2023000601/011	16	2	Low
	C				Y	TUL2023000601/012	24	21	High
10	A	10/18/2022	72.1-73.1	95.7-99.6	Y	TUL2023000601/013	16	16	High
	B				Y	TUL2023000601/014	20	21	High
	C				Y	TUL2023000601/015	12	14	High
11	A	10/25/2022	71.2-71.3	98.0-99.0	Y	TUL2023000613/001	29	10	Moderate
	B				Y	TUL2023000613/002	17	14	High
	C				Y	TUL2023000613/003	20	20	High
12	A	11/1/2022	71.2-71.5	93.1-93.3	Y	TUL2023000613/004	21	9	Moderate
	B				Y	TUL2023000613/005	24	19	High
	C				Y	TUL2023000613/006	23	19	High
13	A	11/8/2022	70.9-72.7	99.0-99.9	Y	TUL2023000613/007	16	5	Low
	B				Y	TUL2023000613/008	6	3	Low
	C				Y	TUL2023000613/009	9	3	Low
14	A	11/15/2022	71.9-72.8	94.0-96.2	Y	TUL2023000613/010	12	7	Moderate
	B				Y	TUL2023000613/011	21	20	High
	C				N	-	-	-	Low
15	A	11/22/2022	71.4-71.9	92.1-93.3	Y	TUL2023000613/012	9	2	Low
	B				Y	TUL2023000613/013	11	6	Low
	C				N	-	-	-	Low

Table 5 90% Humidity Tile Results

90% Ninhydrin - Paper

#	Letter	Date	Temp. Range (°F)	Humidity Range (%)	Ridges Present	AFIS Seach #	AFIS Minutiae Count		Quality
							Before Clean-up	After Clean-up	
1	A	8/30/2022	71.5-72.8	98.6-98.9	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
2	A	9/1/2022	71.1-72.1	99.2-99.5	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
3	A	9/3/2022	71.1-72.3	98.7-99.0	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
4	A	9/5/2022	70.8-72.1	98.0-99.9	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
5	A	9/13/2022	70.9-73.2	99.0-99.1	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
6	A	9/20/2023	70.8-72.7	96.9-98.1	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
7	A	9/27/2022	71.3-72.2	92.1-99.0	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
8	A	10/4/2022	70.8-71.4	91.3-93.0	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
9	A	10/11/2022	70.9-71.7	84.0-91.0	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
10	A	10/18/2022	72.1-73.1	95.7-99.6	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
11	A	10/25/2022	71.2-71.3	98.0-99.0	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
12	A	11/1/2022	71.2-71.5	93.1-93.3	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
13	A	11/8/2022	70.9-72.7	99.0-99.9	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
14	A	11/15/2022	71.9-72.8	94.0-96.2	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low
15	A	11/22/2022	71.4-71.9	92.1-93.3	N	-	-	-	Low
	B				N	-	-	-	Low
	C				N	-	-	-	Low

Table 6 90% Humidity Paper Results

Statistical Analysis

As this project specifically was focused on how humidity impacts latent print quality, we needed to confirm that the actual humidity measured in the experiment was consistent with the desired humidity. We measured the humidity on each day data was collected (Figure 4) and then determined the mean value. We found that the mean humidity for each humidity category (30%, 50%, 90%) was slightly higher than the desired humidity with means and standard deviations of 31.1 +/- 7.1%, 53.9 +/- 4.5%, and 96.3 +/- 3.8% respectively. However, utilizing t-tests we were able to determine that the differences between these means were statistically significant ($p < 0.001$) and therefore still useful for analysis.

Similarly, we assessed the actual temperature on each day that data was collected. This involved recording the high and low temperature for each day and determining the mean values. Statistical analysis (t-tests) indicated there were no statistically significant differences between the mean values of the lower (left) and upper (right) measured temperatures on each day (Figure 5) indicating temperature was consistent across humidity groups throughout the study.

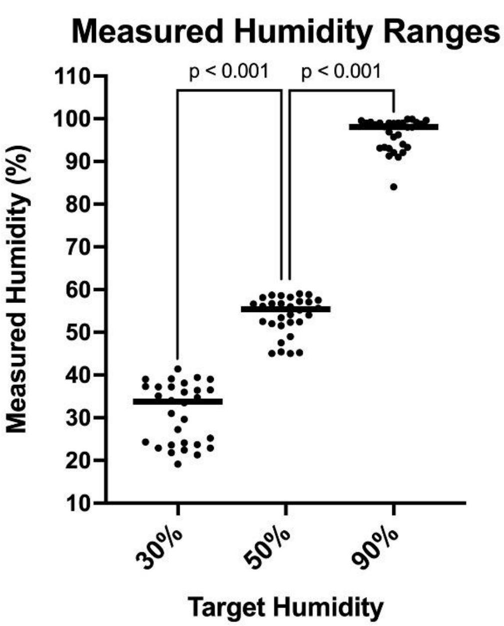


Figure 4 Measured Humidity Ranges

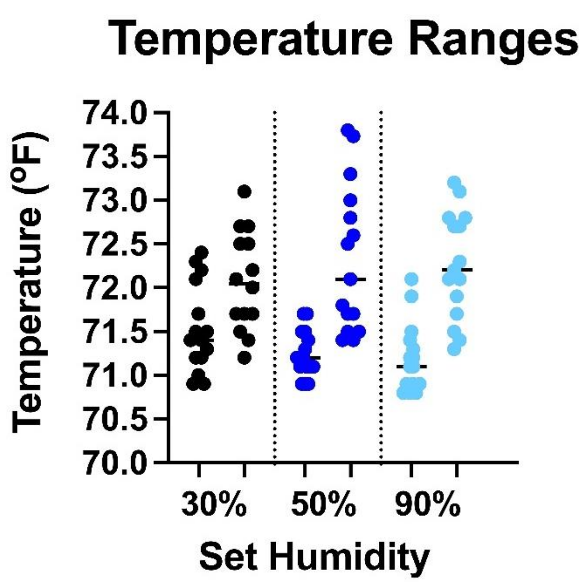


Figure 5 Measured Temperature Ranges

Assessing the statistical differences, or lack thereof, of the environmental factors established validity in experimental conditions allowing for the statistical assessment of latent print quality. We utilized t-tests to assess the overall differences in the number of AFIS minutiae between humidities. We found that there was a statistically significant decrease in the number of minutiae for tile with increases in humidity (Figure 6). This was observed with a comparison of the minutiae count on tile at 30% and 50% humidity and then at 50% and 90% humidity. Similarly, increasing the humidity from 30% to 50% for the paper resulted in a statistically significant decrease in the number of minutiae identified. Note, that the number of minutiae observed was significantly less for paper at 30% humidity compared to tile at 50% humidity (p = 0.049) but there was no statistically significant difference between paper at 30% humidity and tile at 90% humidity (p = 0.576).

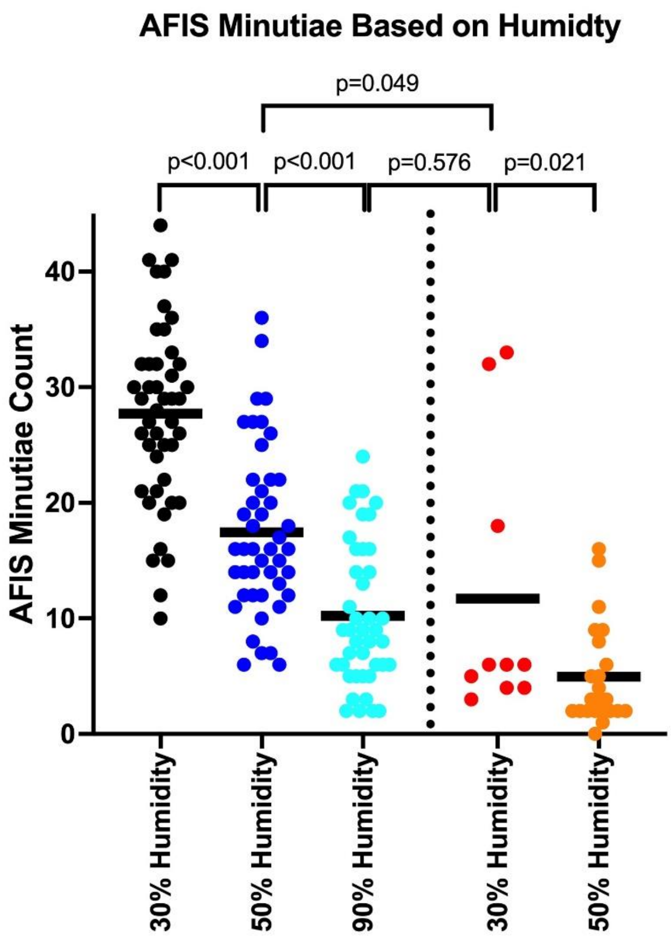


Figure 6 Minutiae Count Based on Humidity

To determine the change in fingerprint quality over time, we utilized linear regression tests. We examined the number of AFIS minutiae we recovered for each print on each day and determined the overall trends for each humidity setting (Figure 7). There was a clear decrease in the number of minutiae recovered over the 12 weeks of the study for all of the tested conditions with the exception of latent prints on tile at 90% humidity. Prints on tile at 90% humidity had a relatively consistent, poor quality. For clarity, we examined this for each substrate (Figure 8) and between paper and tile for the 30% and 50% humidity settings (Figure 9). Note, as there were no observable minutiae on the prints on paper at 90% humidity, data and figures are not included for this group of prints.

A few statistical comparisons were conducted between the tile and paper`. We started by comparing the tile at 90% humidity (fewest minutiae on tile) to the paper at 30% humidity (most minutiae on paper) and found that the number of minutiae did not differ significantly. This indicates to us that the quality of the print did not differ significantly between tile at 90% humidity and paper at 30% humidity. We then backed up to the next humidity setting for tile at 50% and comparted that to the paper at 30% humidity. The number of minutiae for the print on the tile at 50% humidity compared to the number of minutiae on the paper at 30% humidity did differ significantly indicating the quality of the print was higher for tile at 50% humidity than the paper at 30% humidity. This suggests that in general the quality of prints on paper developed with ninhydrin is more effected by increases in humidity than prints on paper developed with black powder.

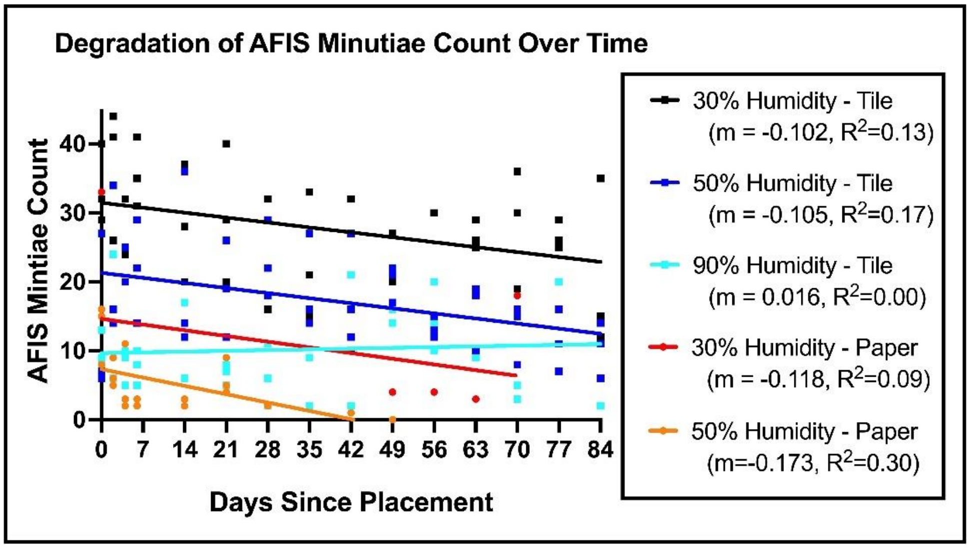


Figure 7 Minutiae Count Over Time

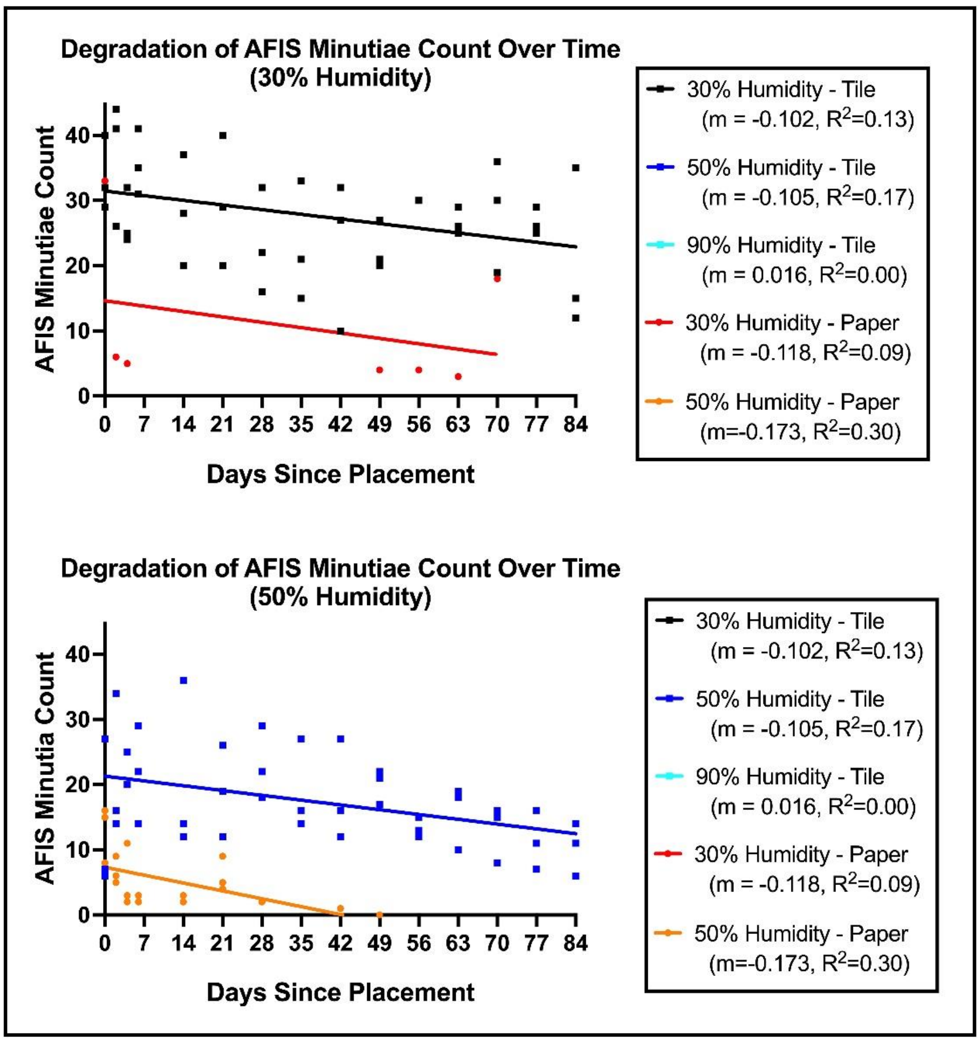


Figure 8 Minutiae Count Over Time by Substrate

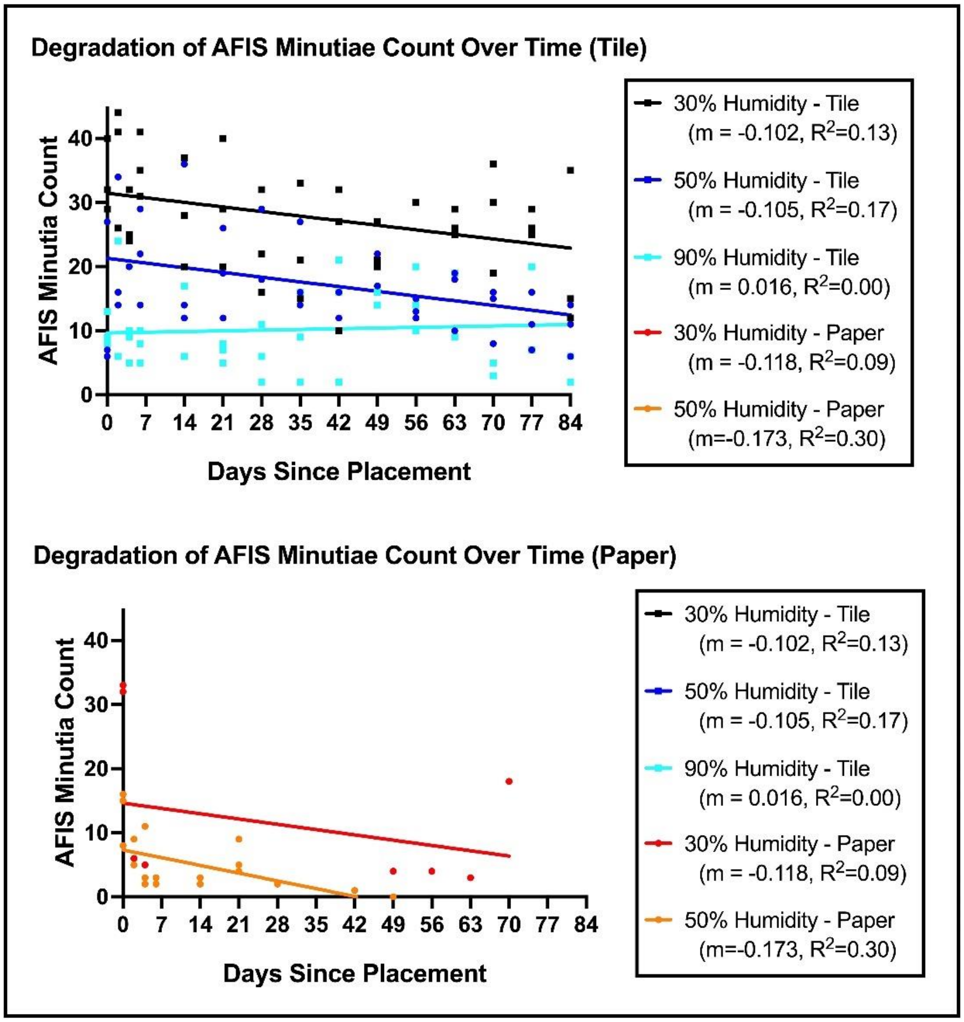


Figure 9 Minutiae Count Over Time by Humidity

Discussion

It was originally hypothesized that humidity would have a noticeable influence on the quality of latent prints over time, which seems to be supported by the results. The prints deposited on the non-porous, white tile surface exhibited a few notable trends. At the 30% and 50% humidities, the quality of the prints and the number of observable minutiae showed a statistically significant decrease over time. Both humidities started with consistently high-quality prints and then the quality decreased with time resulting in moderate or low-quality prints in the second half of the print groups. This is shown in Figure 7 and 12. At 90% humidity, the minutiae count was so varied that it was not possible to discern a trend or to determine if the general quality of the prints increased or decreased with longer exposure time. In fact, statistical analysis indicated a slight increase in the number of minutiae over time. This may reflect that fingerprints degrade over time asymptotically to a poorer quality but in some conditions (like the tile at 90% humidity), this may be difficult to assess given the initial poor quality of the print.

When comparing across humidities, the latent prints on the tiles at 30% humidity had the most consistency in minutiae count as well as the most high-quality fingerprints, while the 90% was the most varied with the most moderate/low quality designations. Examining the images of the prints, the ridges seem to become thicker and more smudged over time, especially for higher humidity. This supports the theory that increased moisture in the air causes more moisture on the print, distorting or smudging the ridges when recovering with black powder. Looking solely at minutiae count, as humidity increased, the number of observable minutiae decreased. This is observed in Figure 6. Minutiae count at 30% was generally higher than 50%, which was higher than 90%. There was also a statistically significant difference between the minutiae count in each humidity group. Although the minutiae count for latent prints at 30% and 50% humidity both decreased over time, the number of observed minutiae at 30% humidity was generally higher overall than the number of minutiae at 50% humidity and the rate of print quality degradation was slightly slower.

For the prints deposited on the porous surface (paper), there was a definite change in quality over time. At both 30% and 50% humidity, prints lost quality with time, eventually having no visible ridges or minutiae. As expected, the prints on paper kept their quality longer at 50% humidity than at 30% humidity. The latent prints on paper at 30% humidity quickly lost visibility after print group 2, while the prints on paper at 50% humidity continued to have visible ridge detail until print group 7. Having more moisture in the air at 50% humidity likely facilitated the ninhydrin development process. Even though the minutiae in the latent prints at 50% humidity kept their visibility longer, the overall minutiae count was lower at 50% humidity than at 30% humidity for paper as shown in Figure 6. Degradation of print quality over time was also much more apparent for the latent prints at 50% humidity. The prints on the porous surface at 90% humidity never exhibited visible ridges or minutiae. During the experimental phase, it was found that the paper became completely saturated from water vapor at the 90% humidity setting, which likely contributed to prints not being recoverable using ninhydrin.

Based on results and statistical evidence, tile was a significantly better substrate from which to recover fingerprints than paper at all humidities. Prints on tile consistently had higher minutiae count and minutiae were recoverable for longer periods of time. For example, the ability to see minutiae on paper at both 30% humidity and 50% humidity was lost by the second week. However, at the same humidities prints on tile were recoverable for the entirety of the experiment. Similarly, minutiae were never observed on paper at 90% humidity, but could be observed on tile. A few statistical tests were run to directly compare minutiae counts and print quality between tile and paper. Results indicated that the minutiae count of prints on tile at 90% humidity (lowest minutiae count for tile) compared to prints on paper at 30% humidity (highest minutiae count for paper) did not differ significantly. However, when the minutiae count for prints on tile at 50% humidity were compared to the minutiae count for prints on paper at 30% paper, there was a statistical significance in the values. We can infer from this that there would also be a statistical significance between minutiae counts for prints on tile at 30% humidity and prints on paper at 30% humidity.

Results and analysis confirm that humidity does have an impact on fingerprint quality for both non-porous and porous surfaces using the development mediums described in this study. Increased humidity causes a decrease in quality for both surface types with the porous surface being more affected than the non-porous. This was different than what was initially hypothesized. Additionally, for both substrates there tended to be a decrease in the quality of latent prints for all humidities over time.

Limitations

There are many potential factors that could affect the quality of fingerprints. This study focused on the impact of humidity on latent prints deposited on non-porous and porous surfaces. Although many factors were controlled (e.g., temperature and humidity), there were some that could not be mitigated. For example, the method of depositing fingerprints. Although the same person and finger and a sebaceous pad were used, it is difficult to have fully consistent pressure or sweat residue for every print. This may be the reason for some of the unusual outliers that occurred during the study.

This study focused solely on humidity due to the presumption that humidity has the largest impact on fingerprint quality. Many other environmental conditions were not tracked, such as light exposure, air quality, etc. Because these factors weren't tested, it cannot be said that humidity alone caused the patterns observed during analysis.

There are also many other recovery methods and many different surface types. This study focused on only two surfaces, tile and paper. Only two processing methods were used, black powder and ninhydrin. Other surfaces and processing methods may react differently to humidity. As an example, the paper at 90% humidity was too wet to recover any prints using ninhydrin. However, a physical developer can be used to recover prints on wet porous surfaces, so it may have been possible to visualize ridge detail if this was used as a processing method. It should be noted that the processing itself and errors in development may have impacted minutiae count.

Lastly, all of the decisions and conclusions made in this paper are based on the interpretation of a graduate student. While courses on latent fingerprint processing and analysis have been completed, the primary investigator is not considered an expert in the field of fingerprint analysis. One area where this may have impacted results is the assessment by the primary investigator that there were no visible ridges on the paper at 90% humidity, so they were not sent to the fingerprint examiner to be uploaded into AFIS. Because of this, the prints on paper at 90% humidity were never viewed by an expert.

Conclusion

In regard to application in the field, it is important for crime scene investigators (CSI's) and lab technicians to understand how environmental conditions impact latent print quality and development. Knowing that humidity can impact print quality, and this can vary by development method, can assist in the decision of processing technique. For example, since ninhydrin does not appear to be very effective at high humidity (the paper becomes too saturated with moisture), it would not be the best method to use when processing paper evidence that has been in a high humidity environment. In this scenario, physical developer may be the best method. Depending on the agency, CSI’s may not have access to all development mediums and tools in their kit at the scene, so they may not be able to process on-scene using the most effective method. This research can bring awareness to agencies about the necessity of training CSIs and lab personnel on how environmental conditions impact latent prints and what development mediums are best under certain conditions. This may also provide support for providing more powders, reagents, and methods for print development to CSIs on-scene.

Environmental studies on fingerprints also show the importance of tracking weather conditions. If prints are not processed on scene, CSI’s should record detailed weather conditions for use in the laboratory to include factors like temperature, humidity, barometric pressure, wind conditions, etc. This research also establishes the need for training for crime scene investigators and lab technicians regarding what methods are best under different conditions. Continued research into the impact of the environment on processing can help develop best methods for print recovery ultimately leading to increased quality in print resolution.

There are many other research studies that could be conducted in the future. For example, analyzing the effect of humidity on different substrates (e.g., semi-porous surfaces or additional porous/non-porous surfaces). This study only examined one porous (white paper) and one non-porous (white tile) surface. There are also additional processing methods that were not evaluated. For example, cyanoacrylate fuming, fluorescent powders/dyes, SPR, and DFO. As stated previously, processing latent prints on paper with physical developer could show different results from ninhydrin. This might be especially effective for high humidities where the paper becomes saturated since physical developer is useful on wet porous surfaces. Humidity is also very important for the cyanoacrylate fuming process. It would be interesting to evaluate how continued exposure to humidity in a fuming chamber might influence latent print quality or how exposure to variations in humidity prior to processing with cyanoacrylate might impact latent print development and quality. There are also many other environmental factors that could be tested. This could include varying temperatures, light exposure (artificial and/or UV), air pressure, etc. Knowing what environmental factors and what combinations of factors influence the quality of latent prints the most and how these factors impact development methods have important implications in the field. Also, examining the impact of environment on patent and plastic prints might also be valuable.

References

Alcaraz-Fossoul, J. D., Patris, C. M., Muntaner, A. B., Feixat, C. B., & Badia, M. G. (2013). *Determination of latent fingerprint degradation patterns – a real fieldwork study*. International Journal of Legal Medicine, 127(4), 857–870. https://doi.org/10.1007/s00414-012-0797-0

Archer, N. E., Charles, Y., Elliott, J. A., & Jickells, S. (2005). *Changes in the lipid composition of latent fingerprint residue with time after deposition on a surface*. Forensic Science International, 154(2), 224–239. https://doi.org/10.1016/j.forsciint.2004.09.120

Bell, S. F., Barry, A. J., & Shaler, R. C. (2008). *Encyclopedia of forensic science: Vol. Rev. ed,* 261. Facts on File, Inc.

Bumbrah, G. S. (2016). *Small particle reagent (SPR) method for detection of latent fingermarks: A review*. Egyptian Journal of Forensic Sciences, 6(4), 328–332. https://doi.org/10.1016/j.ejfs.2016.09.001

Cadd, S., Islam, M., Manson, P., & Bleay, S. (2015). *Fingerprint composition and aging: A literature review*. Science & Justice, 55(4), 219–238. https://doi.org/10.1016/j.scijus.2015.02.004

Colella, O., Miller, M., Boone, E., Buffington-Lester, S., Curran, F.J., III & Simmons, T. (2020), *The effect of time and temperature on the persistence and quality of latent fingerprints recovered from 60-watt incandescent light bulbs*. Journal Forensic Science, 65, 90-96. https://doi-org.libproxy.uco.edu/10.1111/1556-4029.14133

Dominick, A. J., Daéid, N. N., Bleay, S. M., & Sears, V. (2009). *The recoverability of fingerprints on paper exposed to elevated temperatures - part 1: Comparison of enhancement techniques*. Journal of Forensic Identification, 59(3), 325-339. Retrieved from https://libproxy.uco.edu/login?url=https://www.proquest.com/scholarly-journals/recoverability-fingerprints-on-paper-exposed/docview/194839756/se-2

Evidence-Processing. (n.d.). Minnesota Bureau of Criminal Apprehension. https://dps.mn.gov/divisions/bca/bca-divisions/forensic-science/Pages/evidence-processing.aspx

Exploring the history of forensic science through time. (n.d.). Incognito Forensic Foundation. https://ifflab.org/history-of-forensic-science/

Hicklin, R. A., Buscaglia, J., Roberts, M. A., Meagher, S. B., Fellner, W., Burge, M. J., Monaco, M., Vera, D., Pantzer, L. R., Yeung, C. C., & Unnikumaran, T. N. (2011). *Latent fingerprint quality: A survey of examiners*. Journal of Forensic Identification, 61(4), 385.

James, S. H., Nordby, J. J., & Bell, S. (Ed.). (2014). *Forensic Science: An introduction to scientific and investigative techniques.* Taylor & Francis Group, LLC.

Keogh, E. (2001) *An Overview of the Science of Fingerprints*. Anil Aggrawal's Internet Journal of Forensic Medicine and Toxicology, 2(1). https://anilaggrawal.com/ij/vol_002_no_001/papers/paper005.html

Paine, M., Bandey, H. L., Bleay, S.M., & Willson, H. (2011). *The effect of relative humidity on the effectiveness of the cyanoacrylate fuming process for fingermark development and on the microstructure of the developed marks*. Forensic Science International, 212(1), 130–142. https://doi.org/10.1016/j.forsciint.2011.06.003

Siegel, S. (2017). *Latent print comparison with advanced topics.* Houston Forensic Science Center.

Sodhi, G. S., & Kaur, J. (2001). *Powder method for detecting latent fingerprints: A review*. Forensic Science International, 120(3), 172–176. https://doi.org/10.1016/s0379-0738(00)00465-5

Watson, C. (2008). *Slap fingerprint segmentation evaluation II*. NIST. https://www.nist.gov/system/files/documents/2022/02/03/slapsegii_testplan_061208.pdf

Wilshire, B. (1996). *Advances in fingerprint detection*. Endeavour (New Series), 20(1), 12–15. https://doi.org/10.1016/0160-9327(96)10005-3

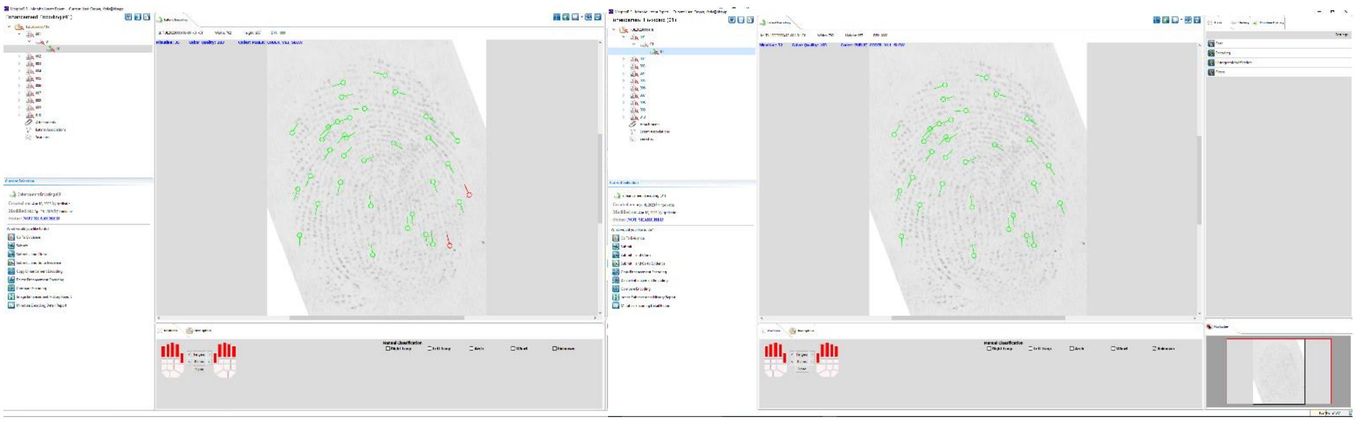
Yamashita, B. & French, M. (2011). Latent print development. In A. McRoberts (Ed.), *The Fingerprint Sourcebook* (pp. 155-222). National Institute of Justice.

Appendix I

Note: Any numbers or letters that are skipped were fingerprints that had no visible minutiae

30% Paper

<u>*Before Clean-Up*</u> | <u>*After Clean-Up*</u>



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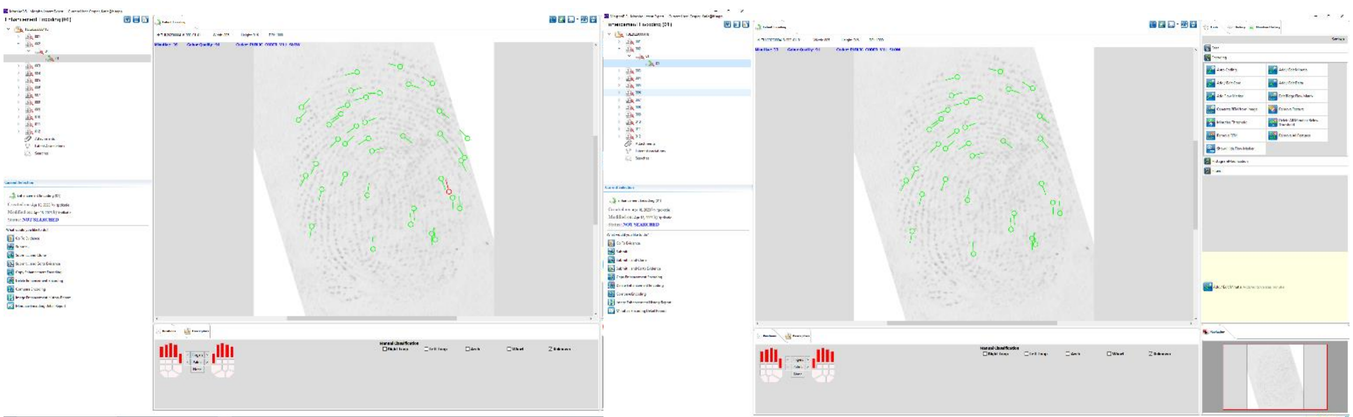

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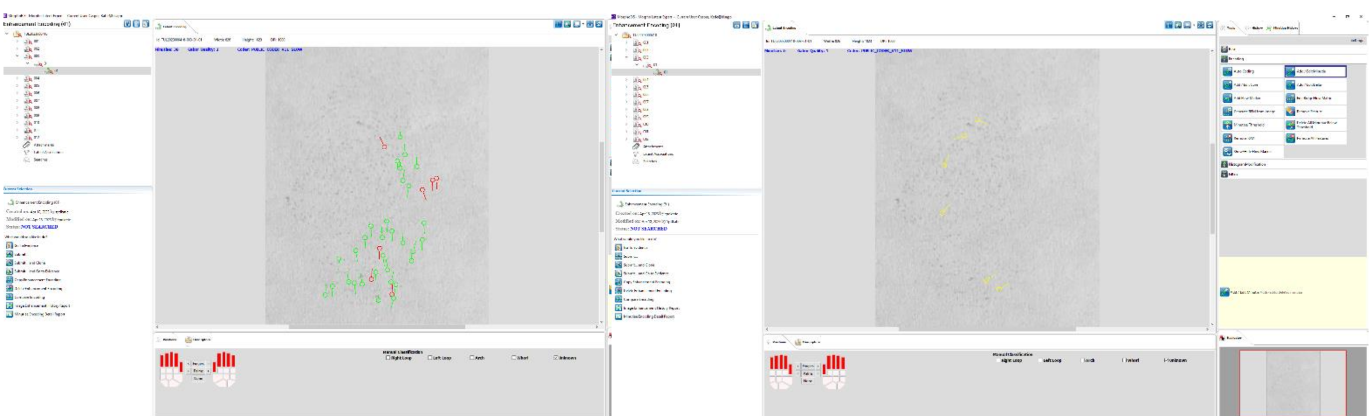

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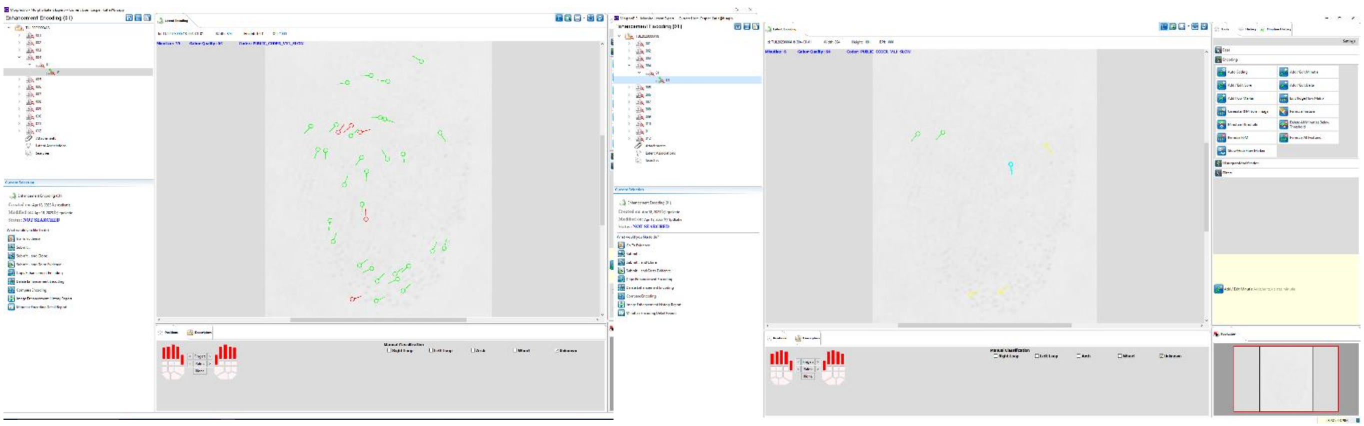

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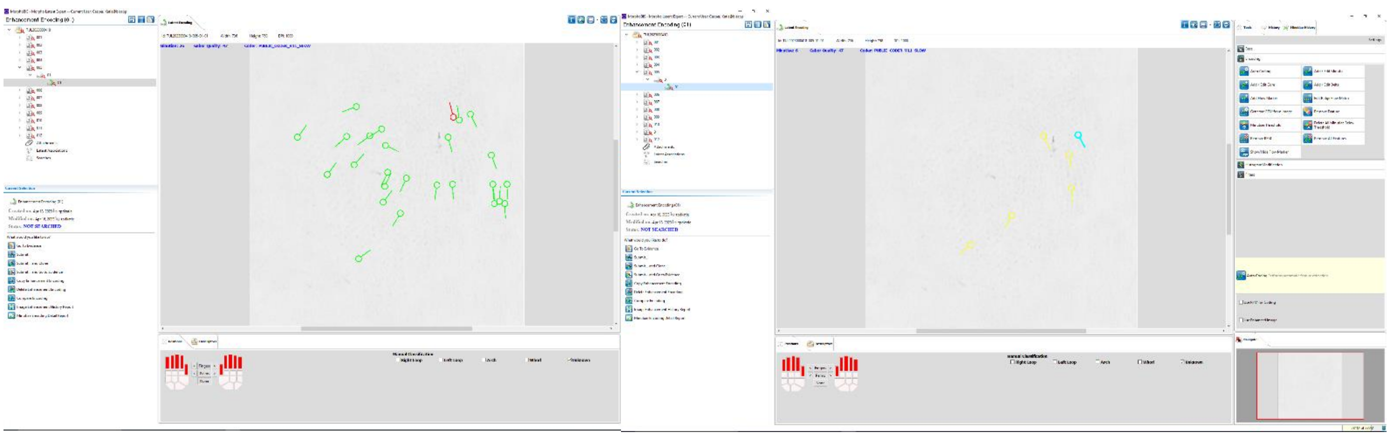

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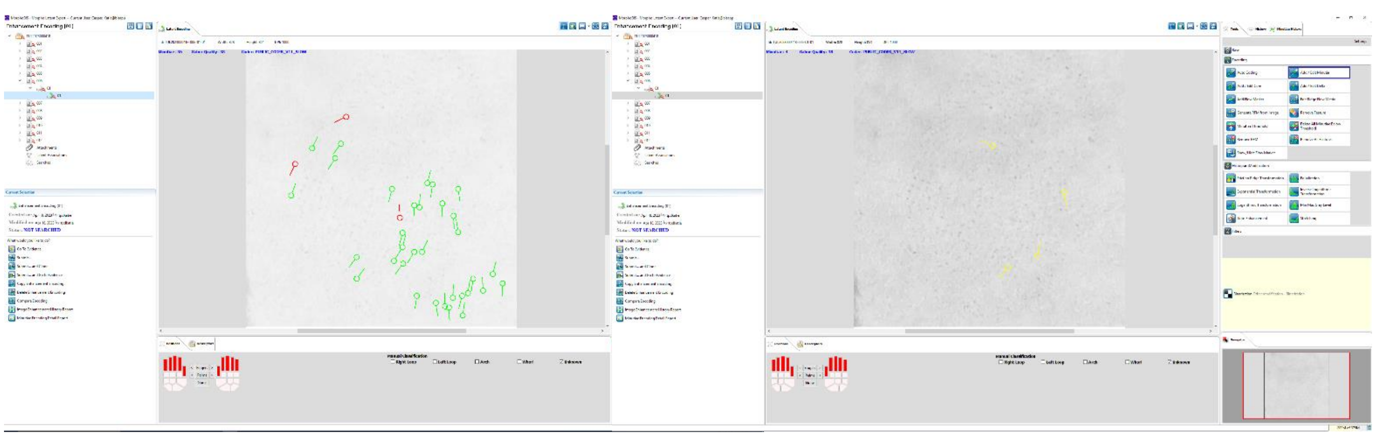

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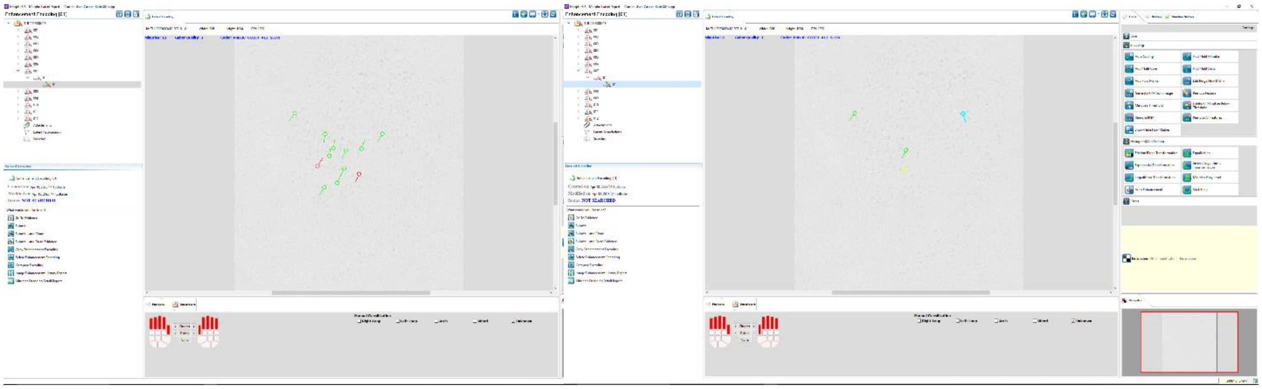

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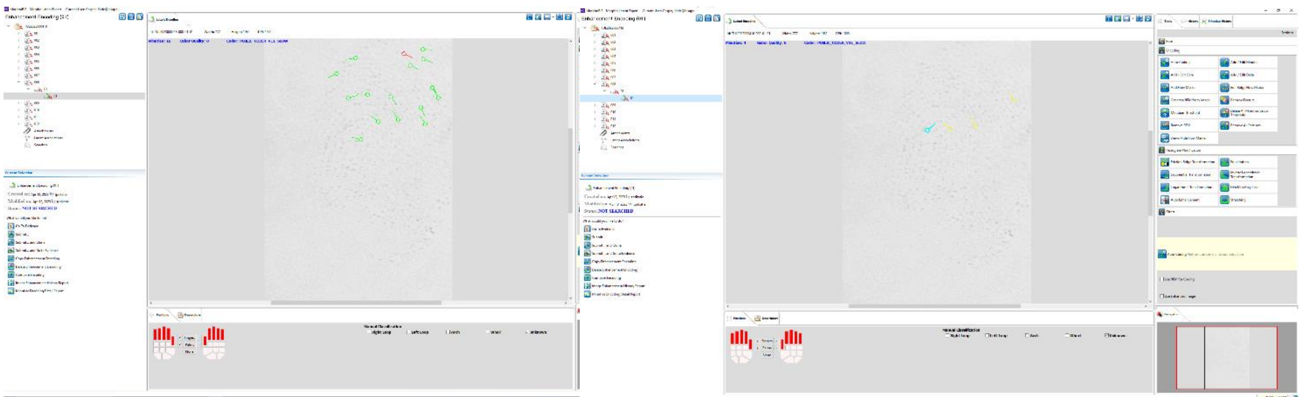

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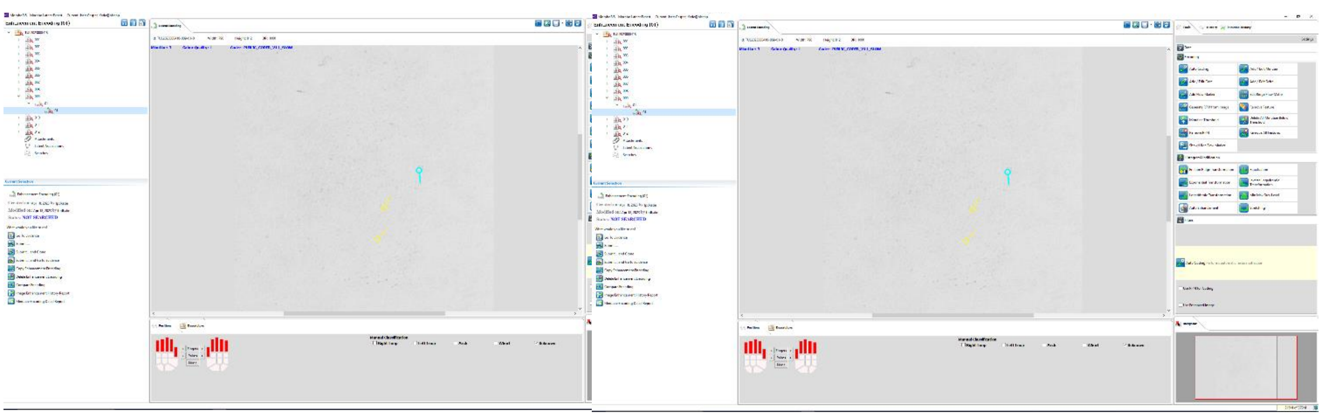

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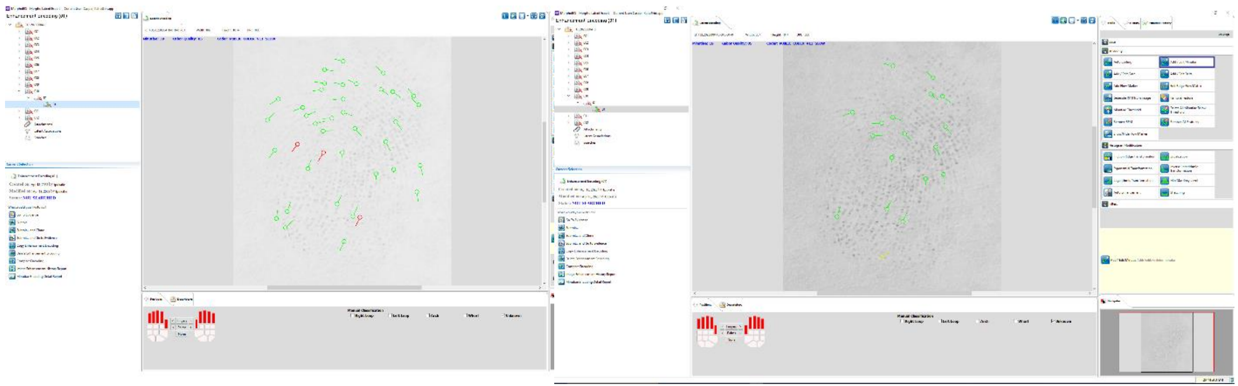

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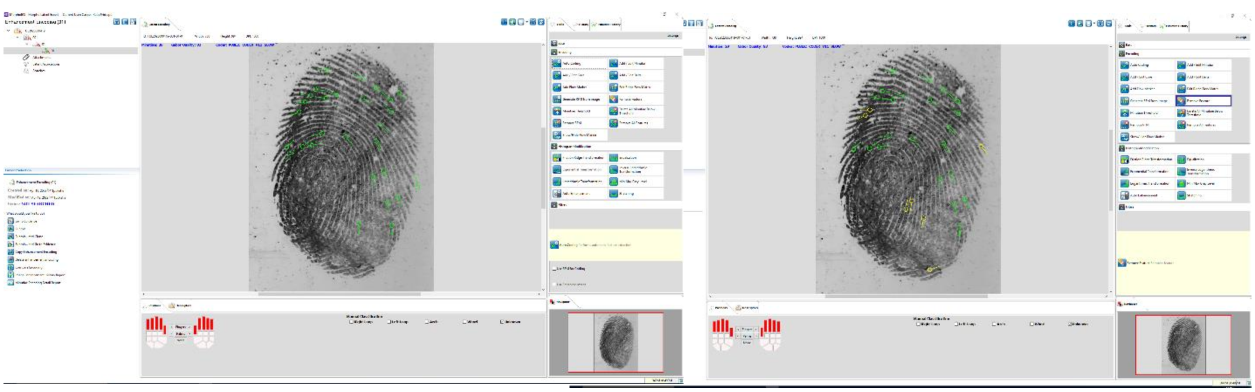

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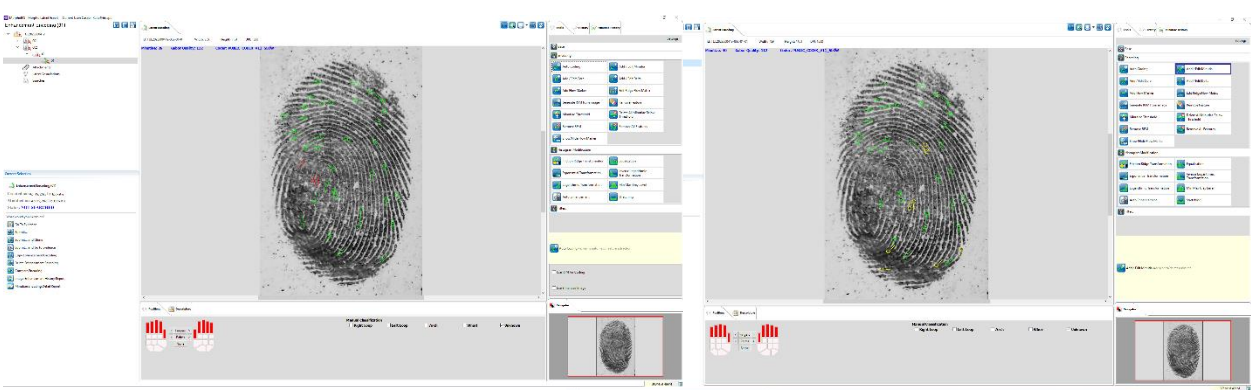

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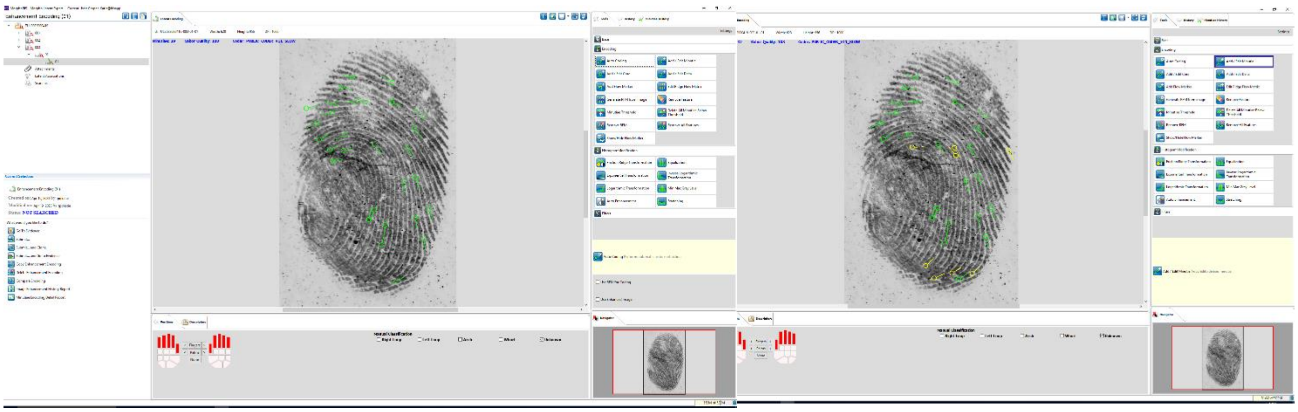

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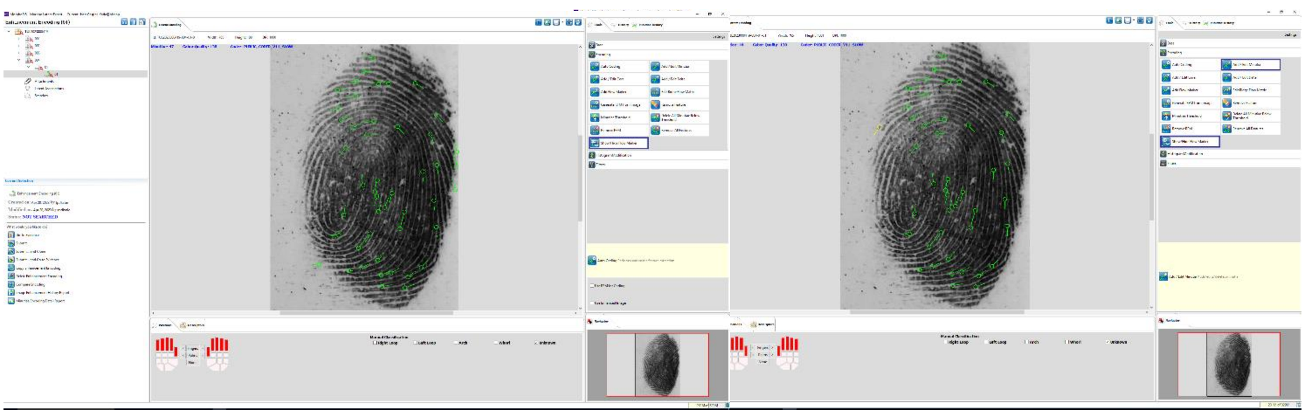

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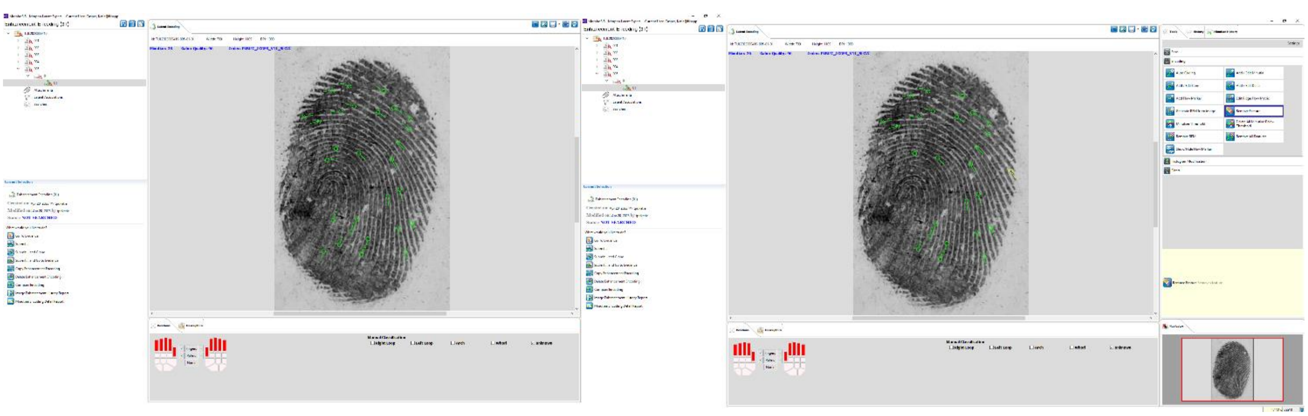

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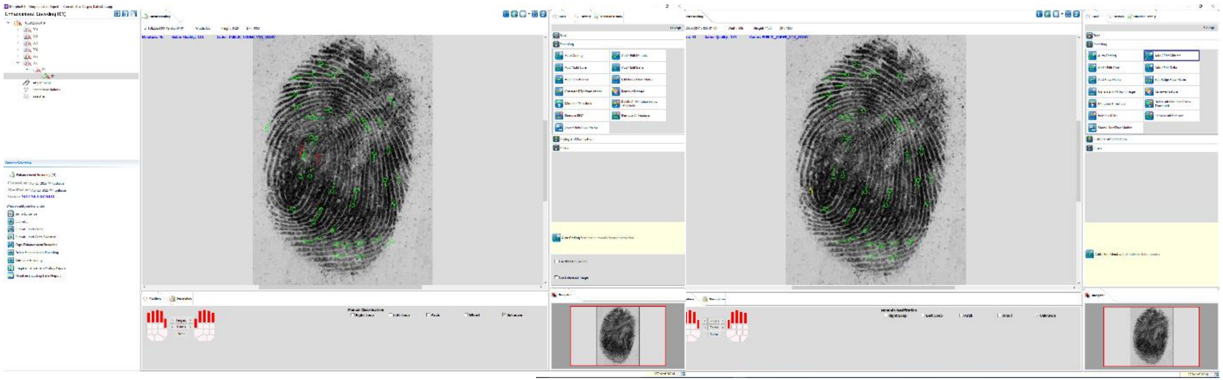

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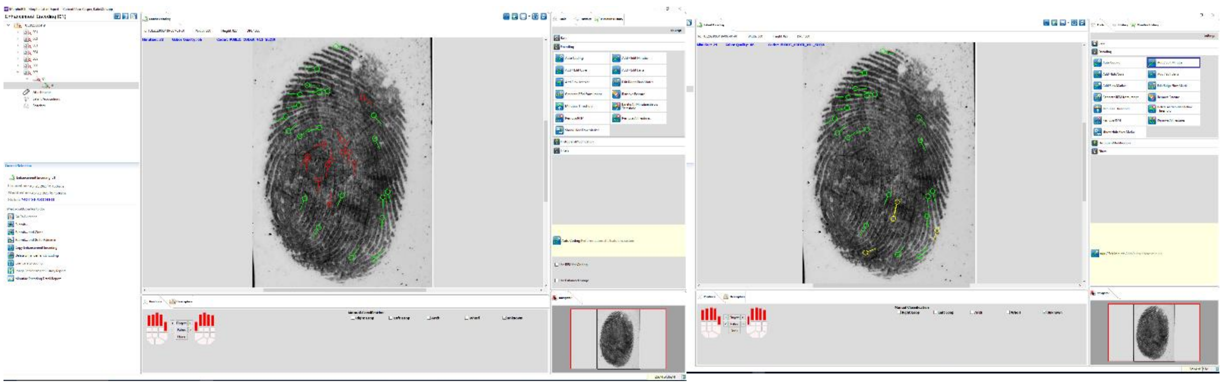

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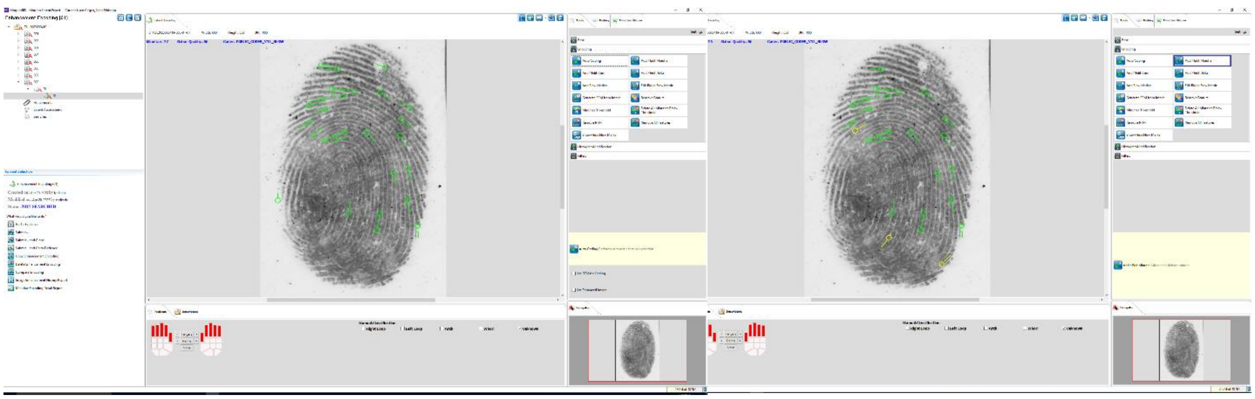

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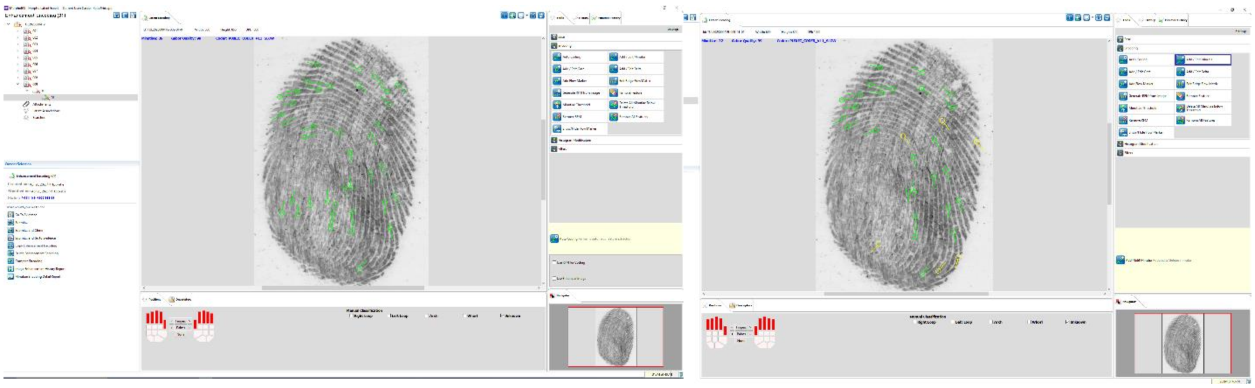

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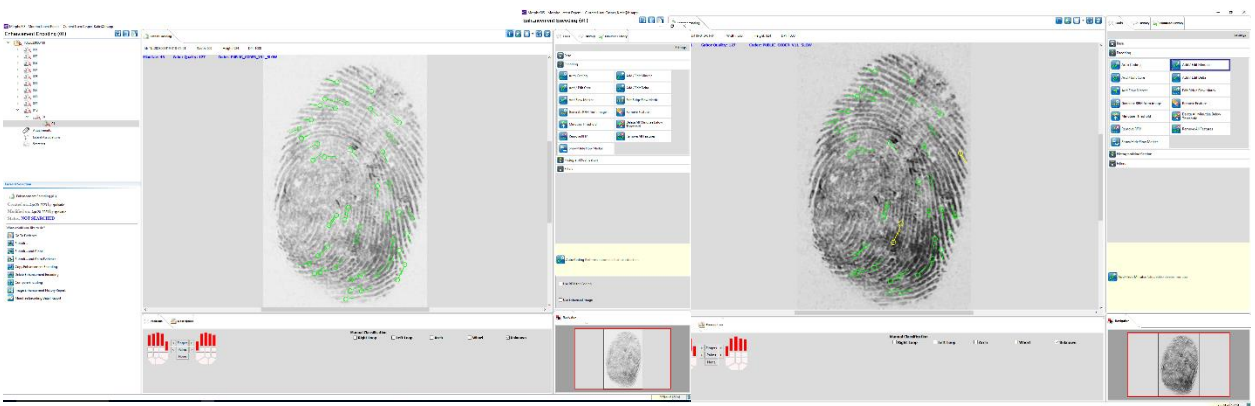

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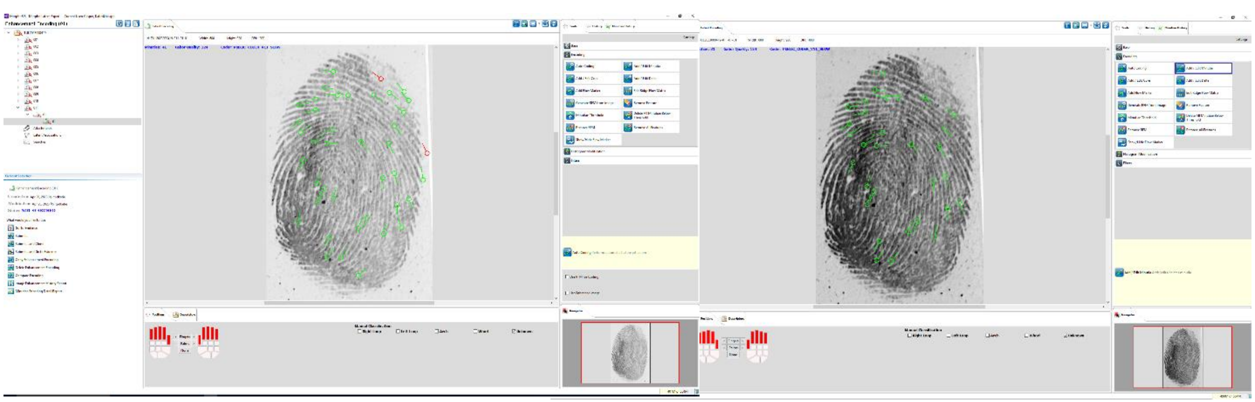

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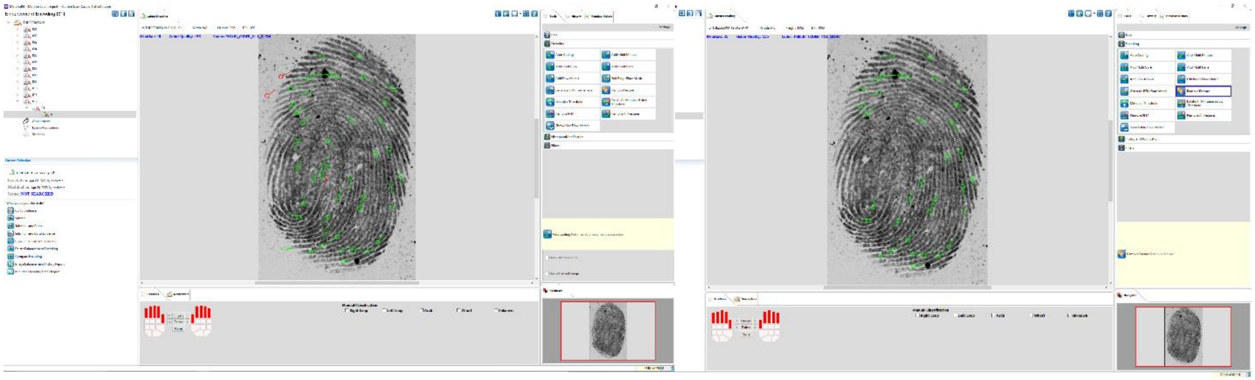

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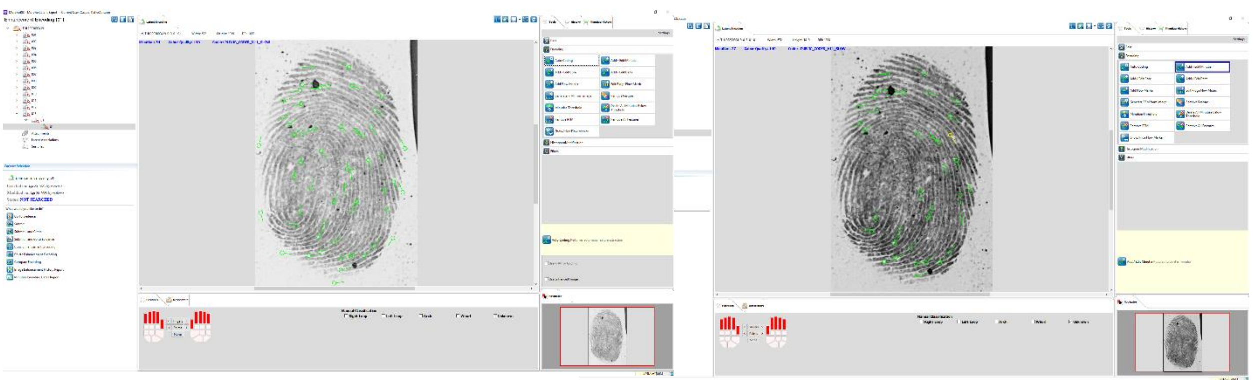

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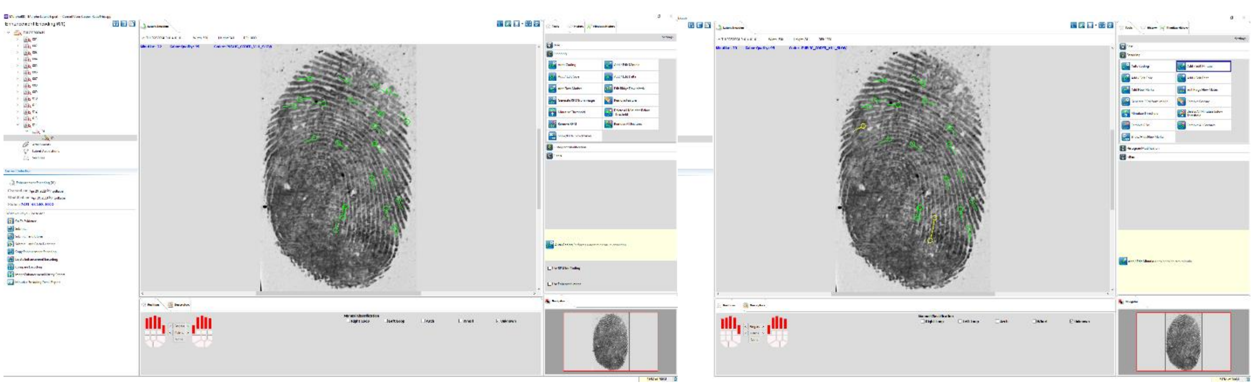

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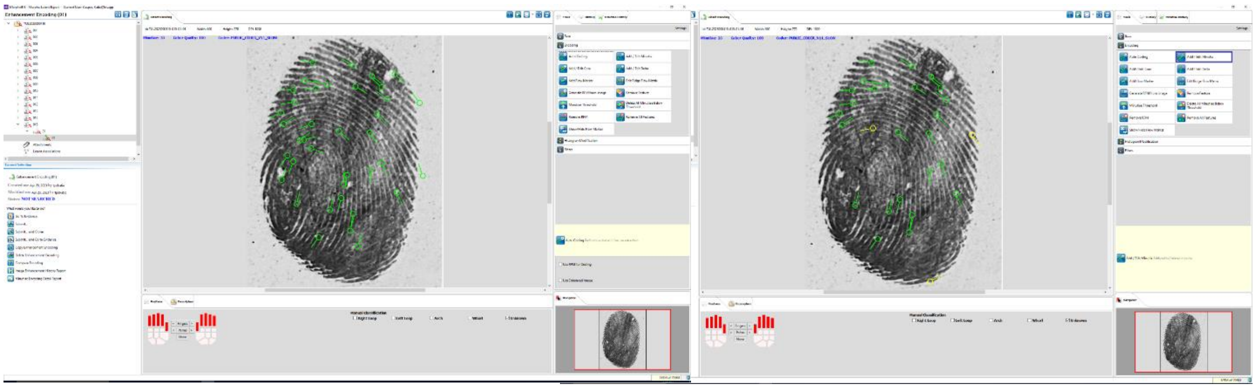

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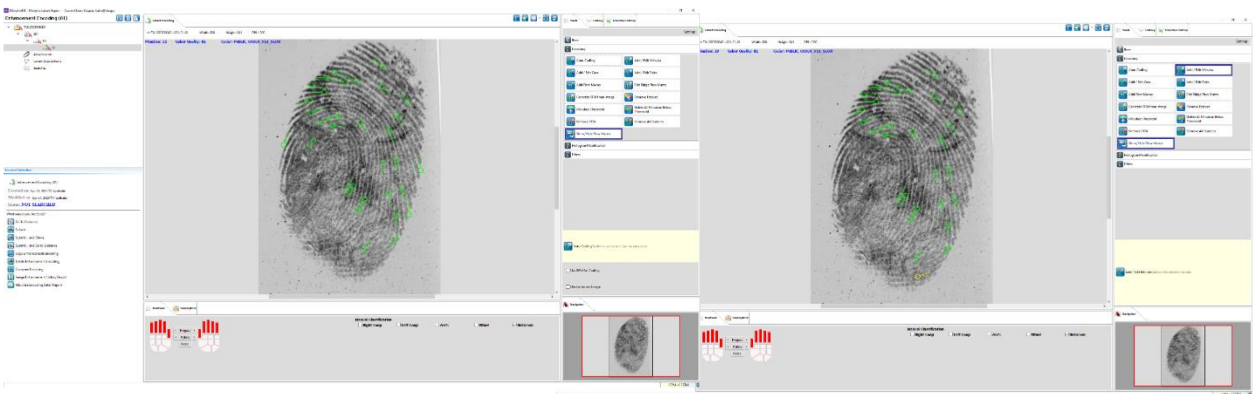

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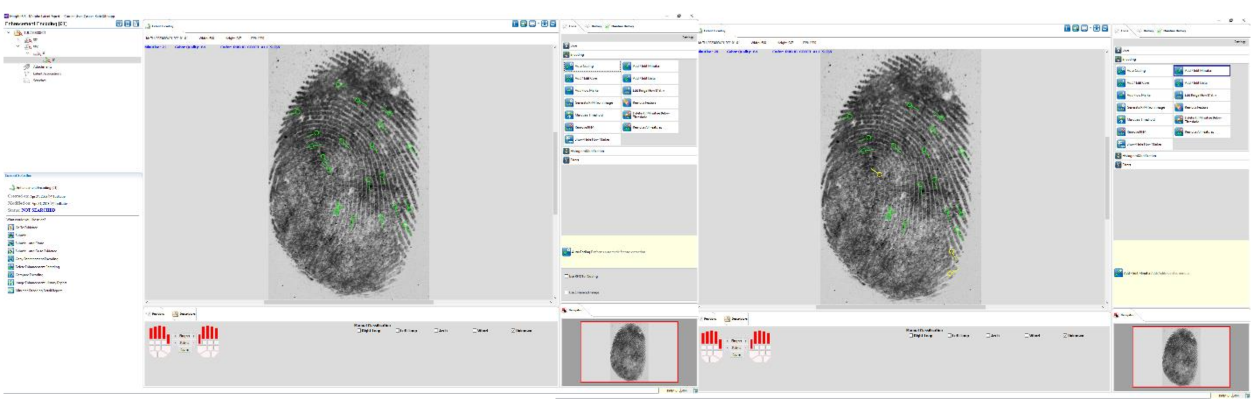

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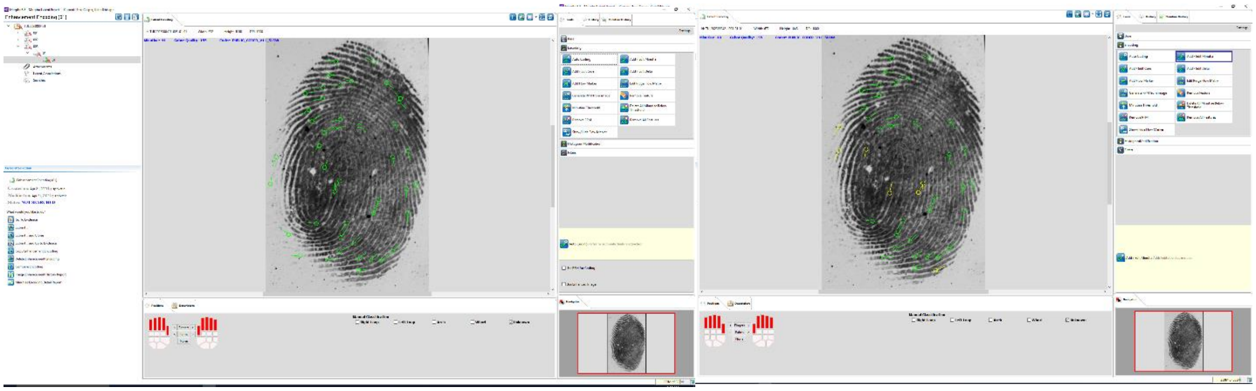

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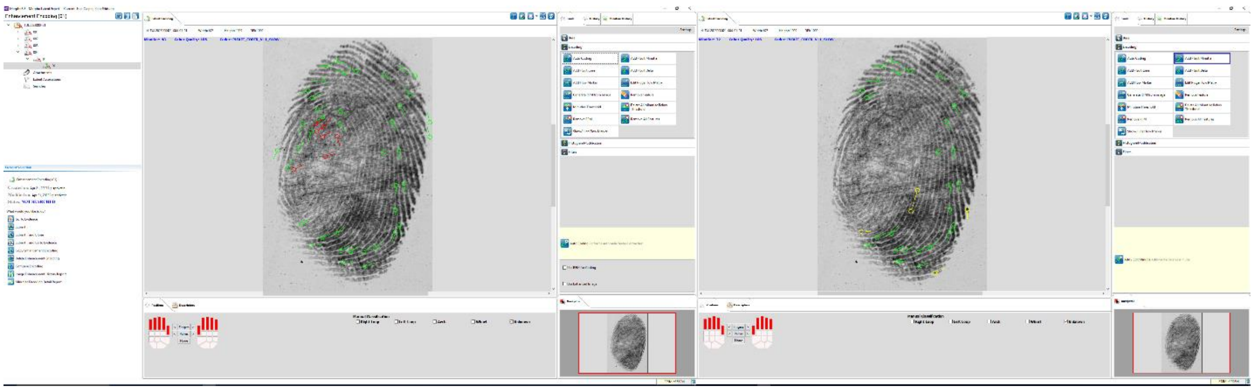

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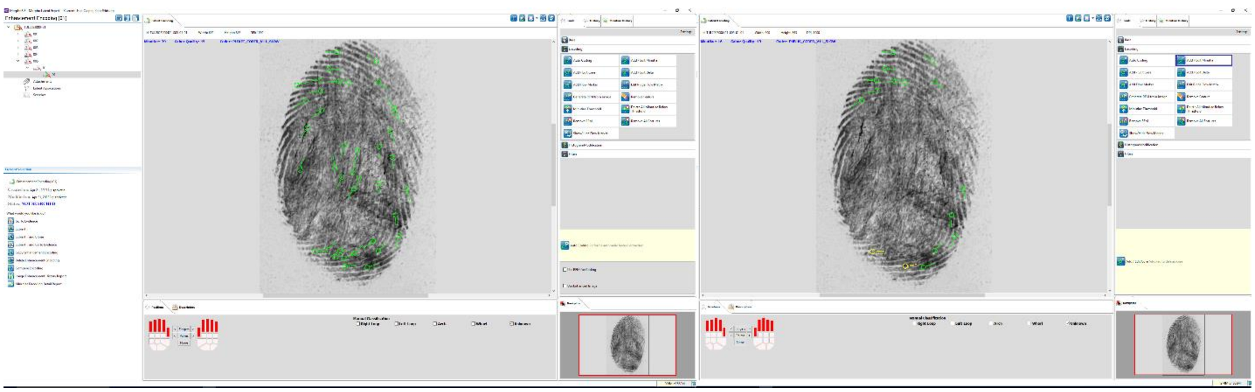

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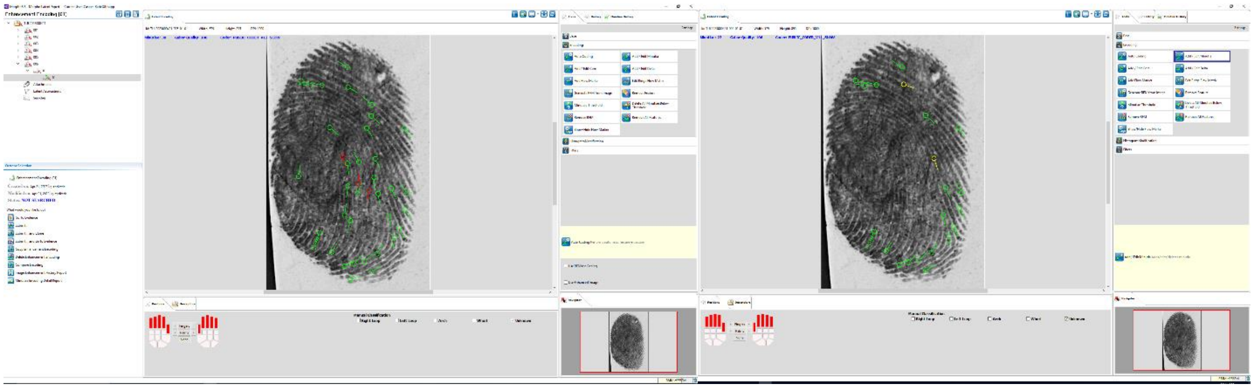

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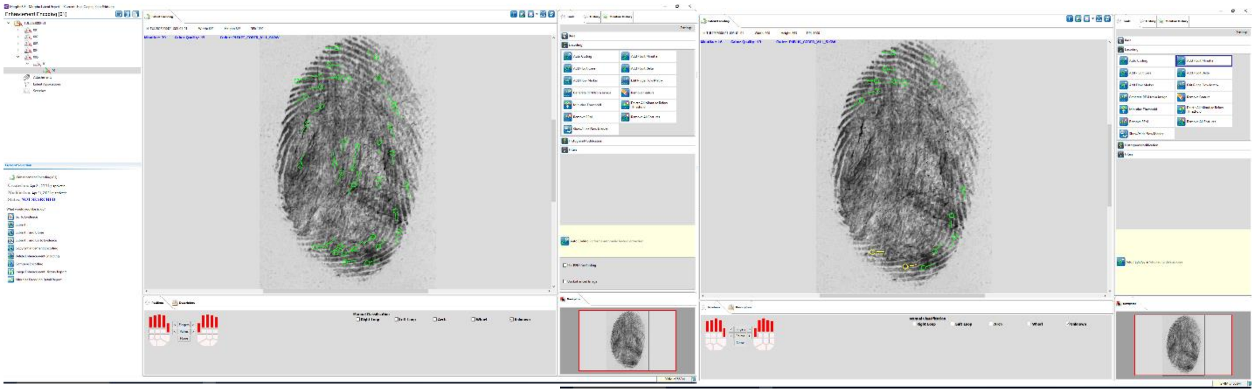

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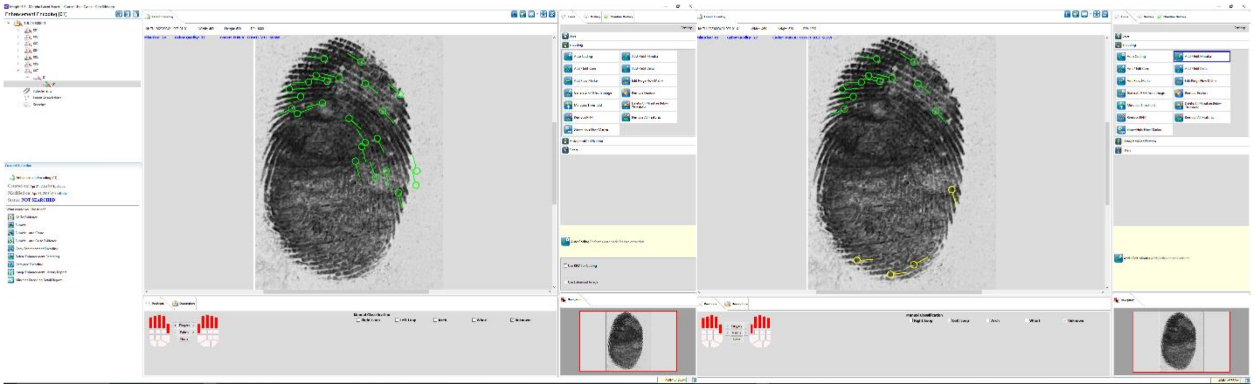

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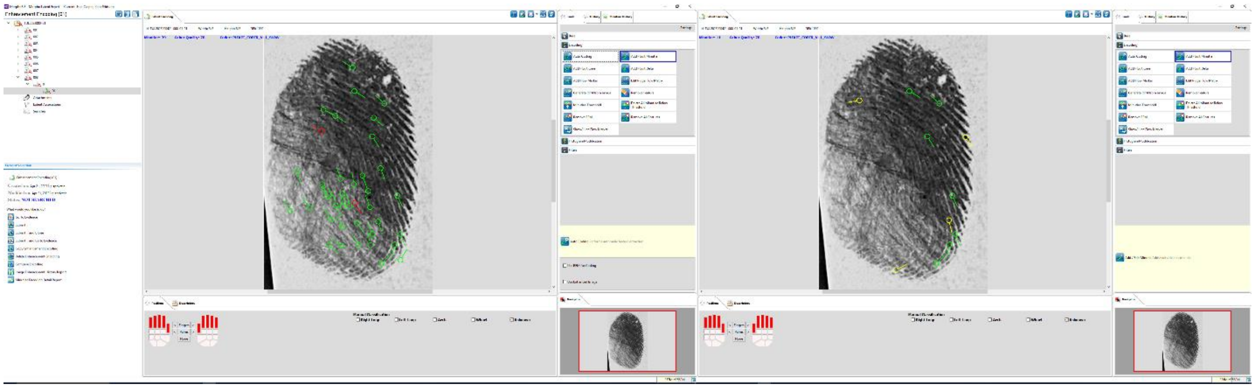

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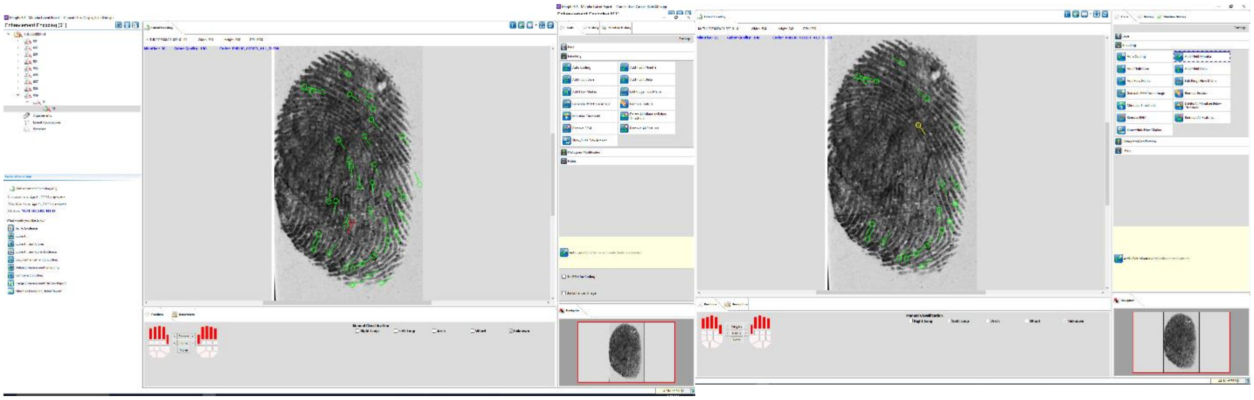

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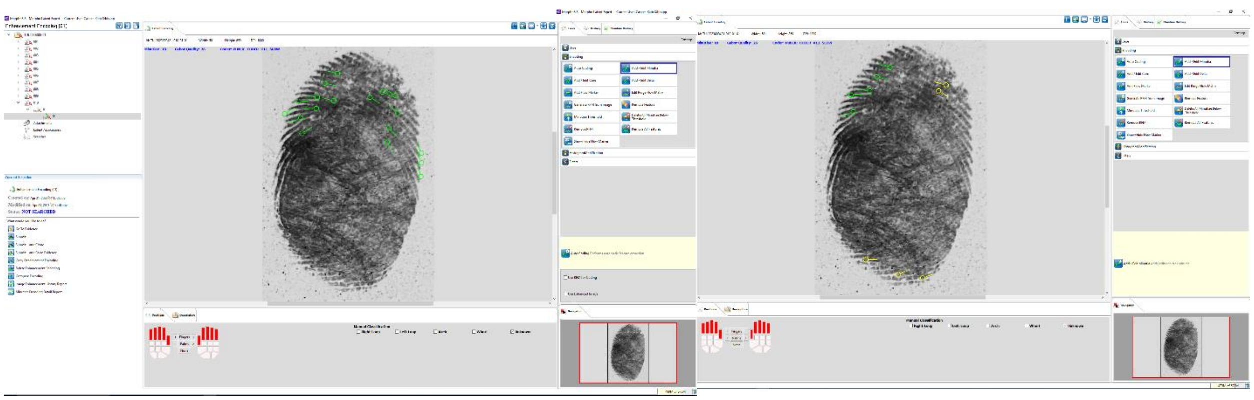

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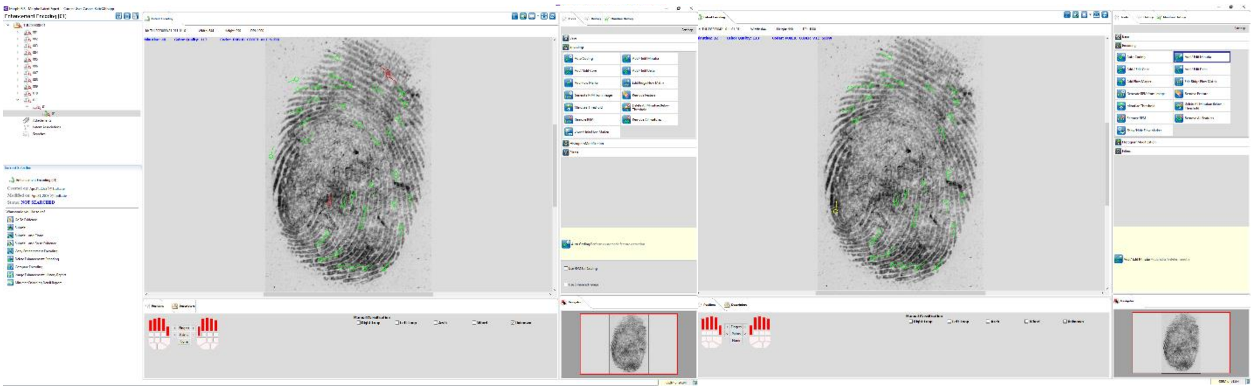

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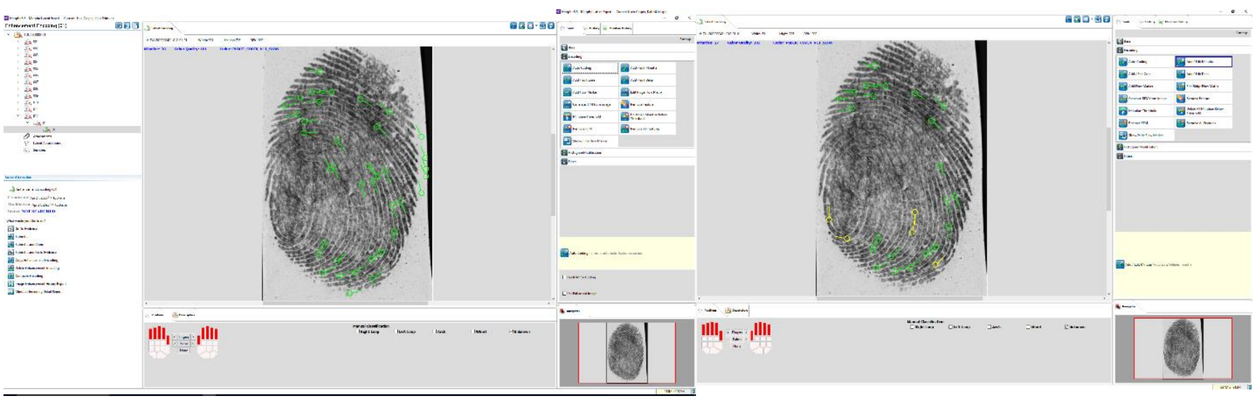

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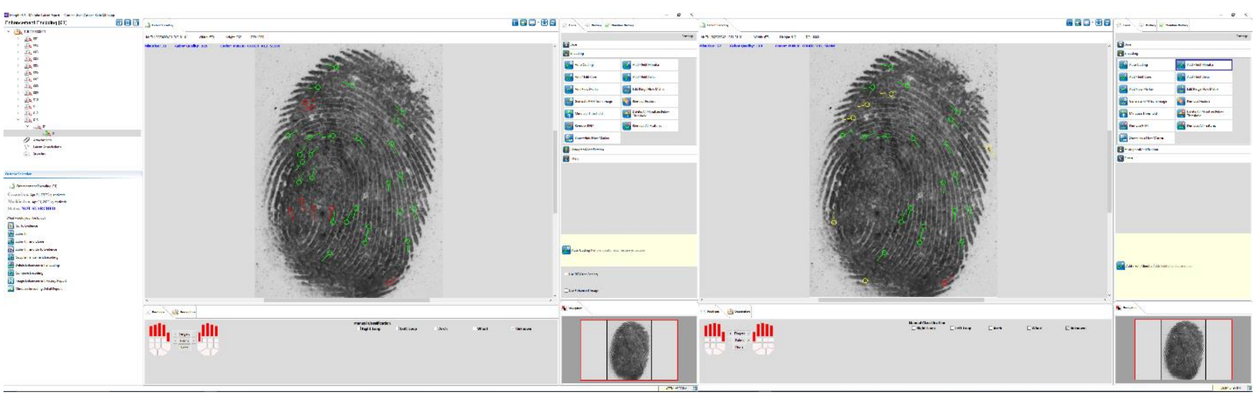

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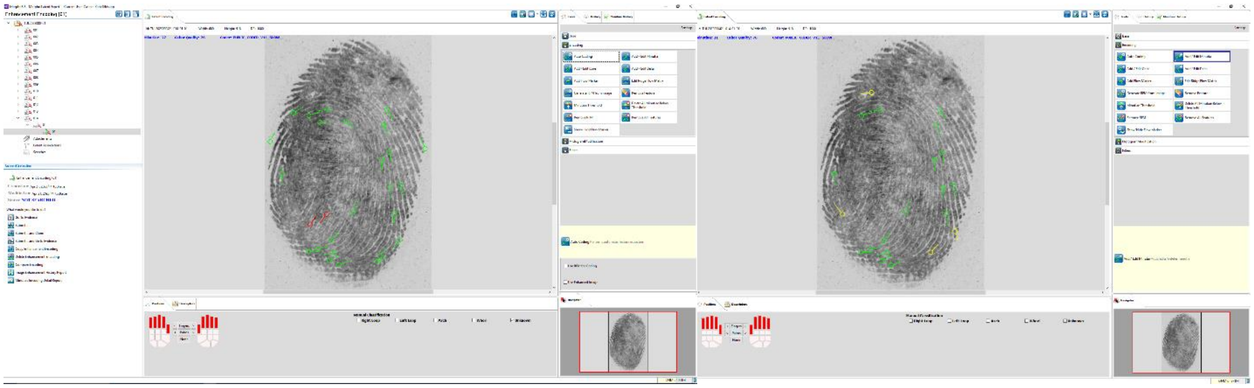

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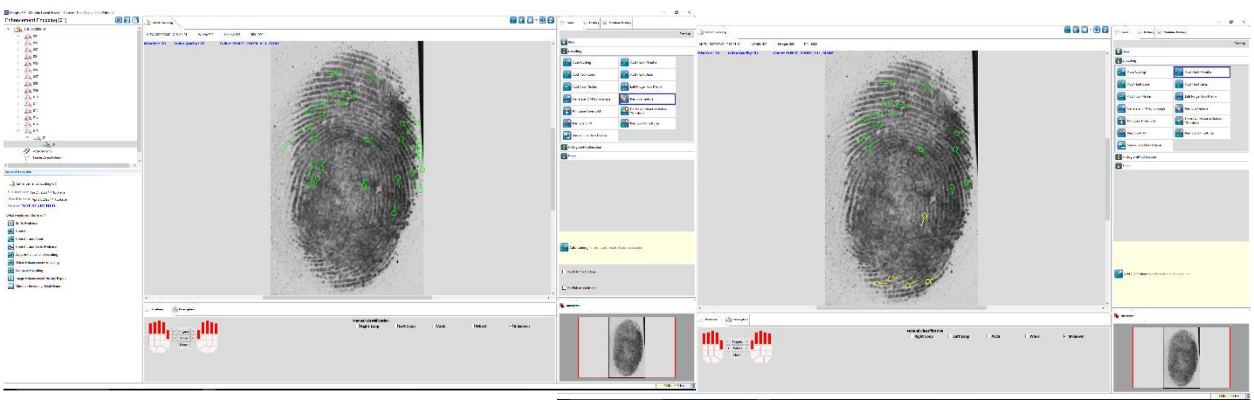

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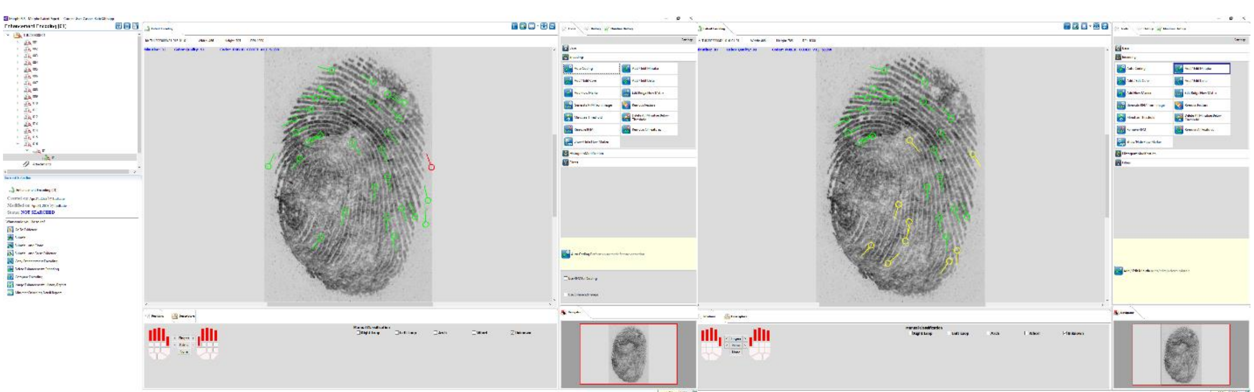

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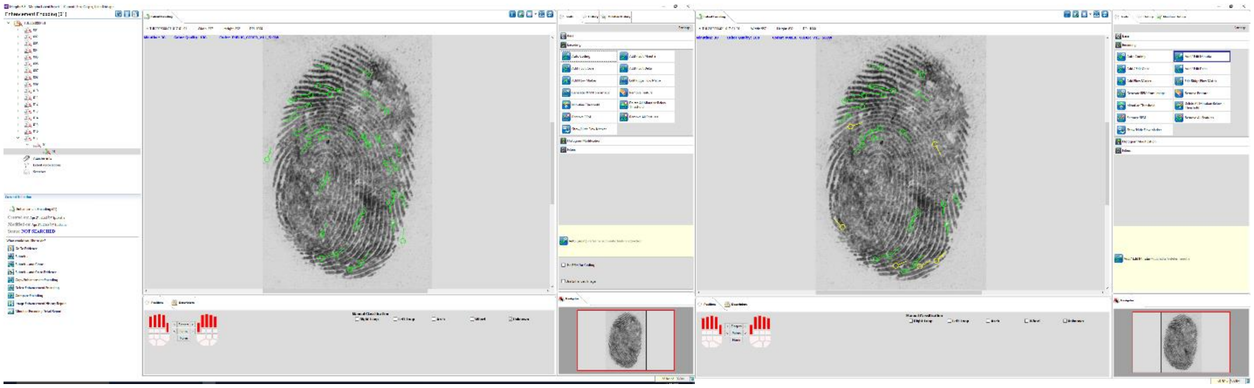

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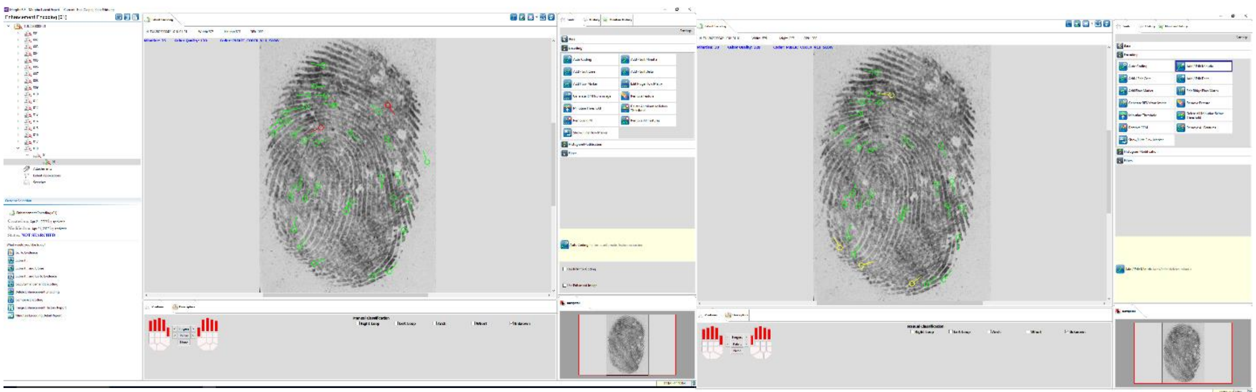

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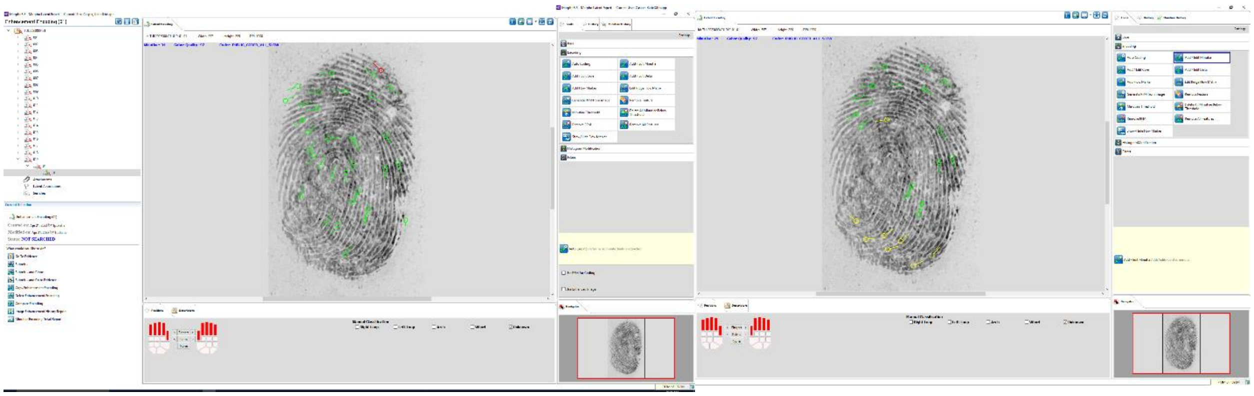

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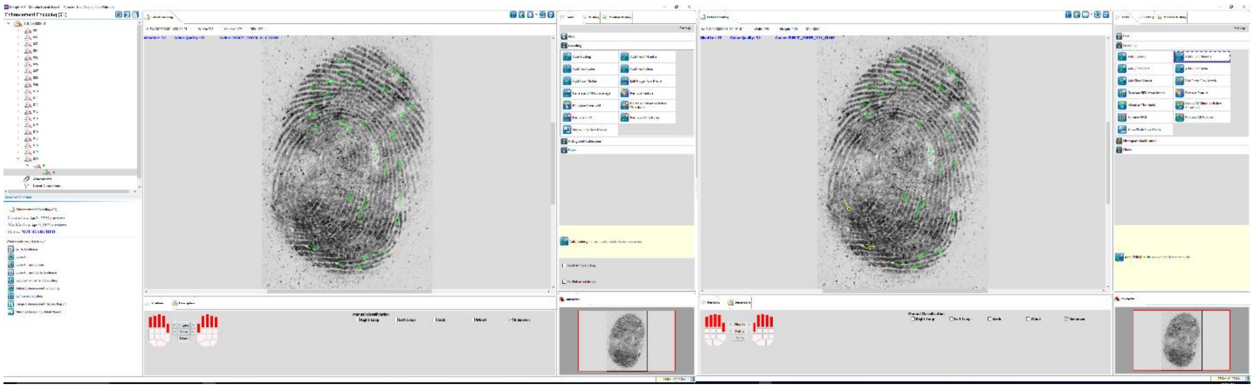

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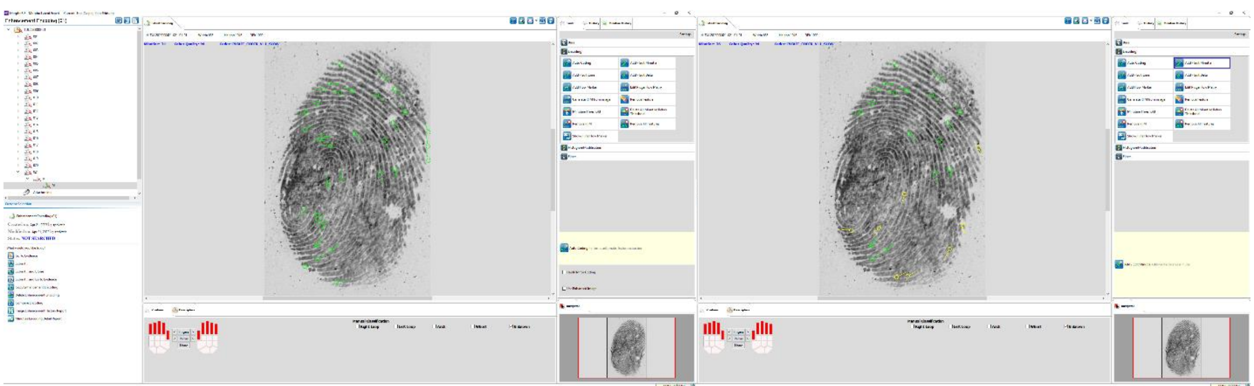

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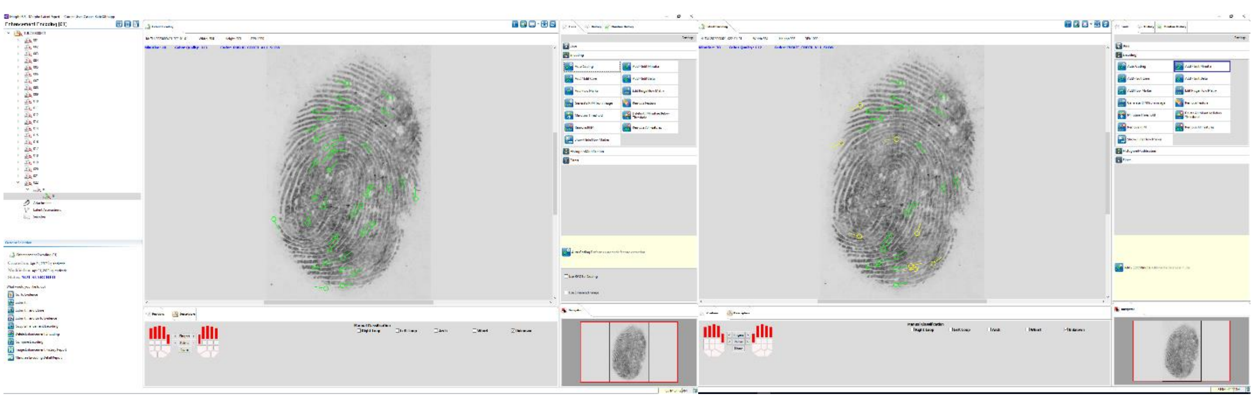

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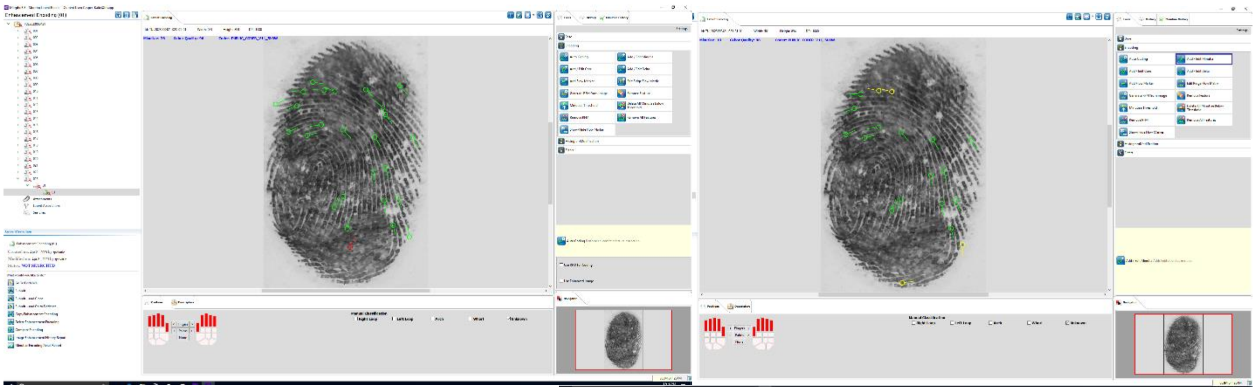

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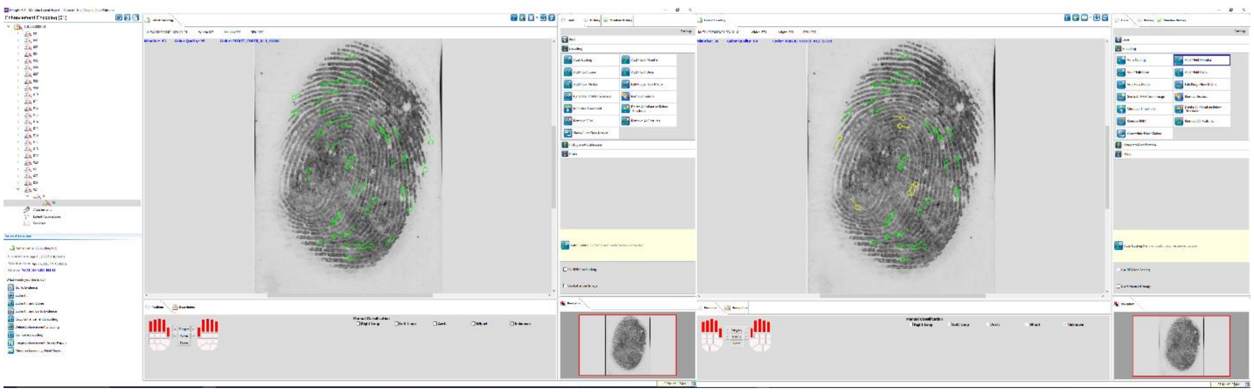

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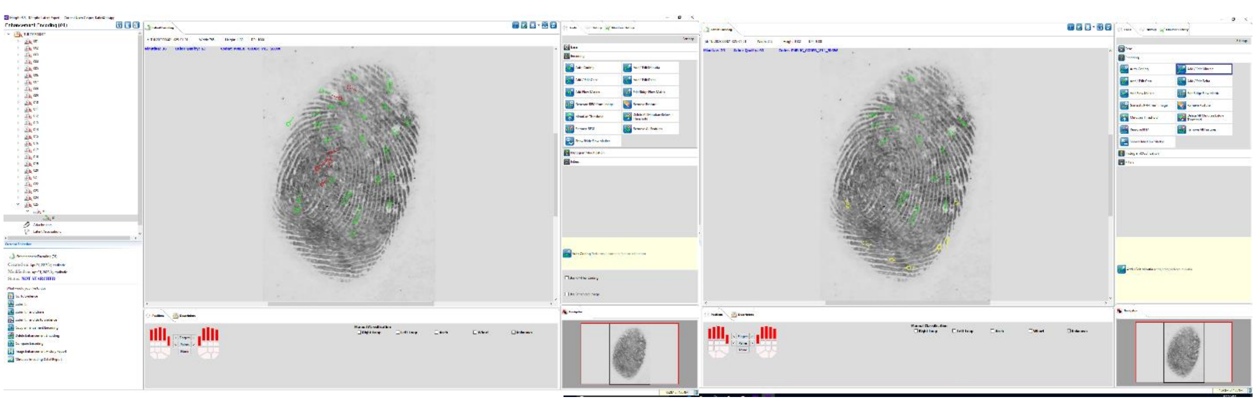

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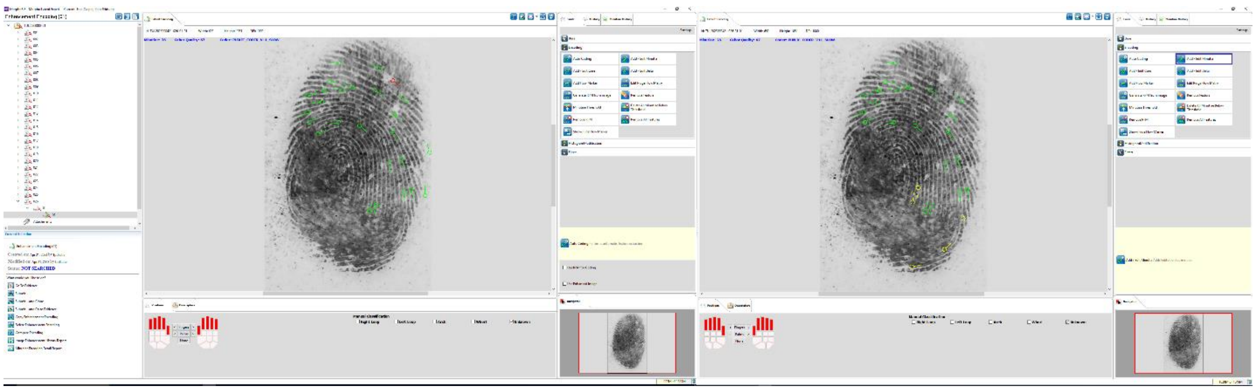

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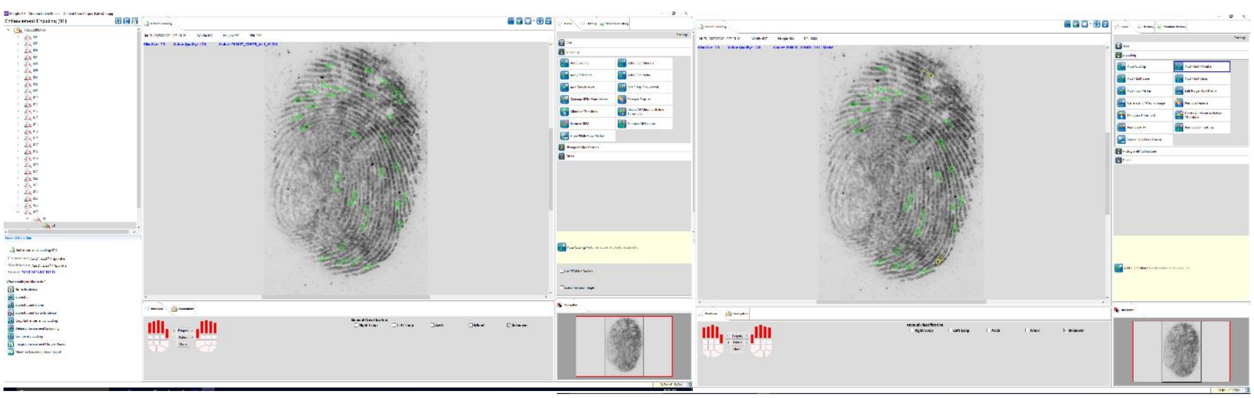

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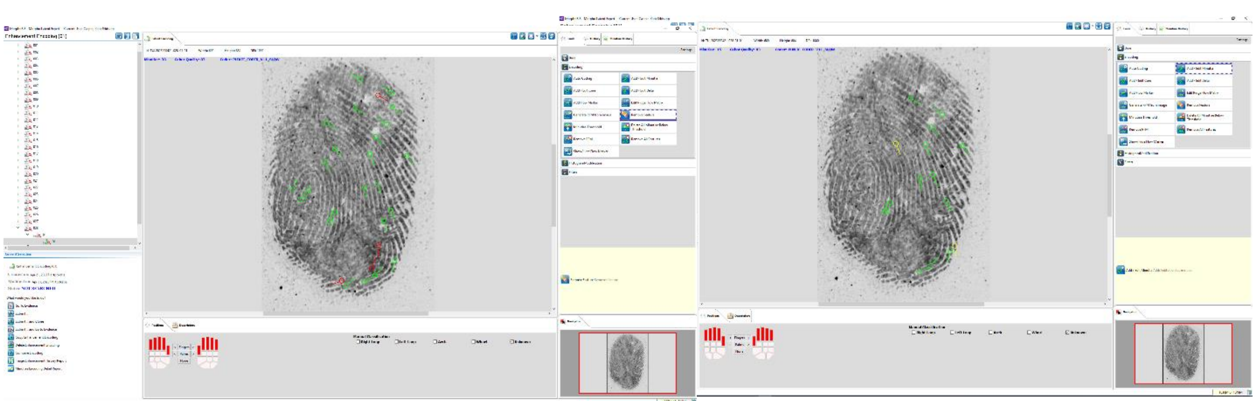

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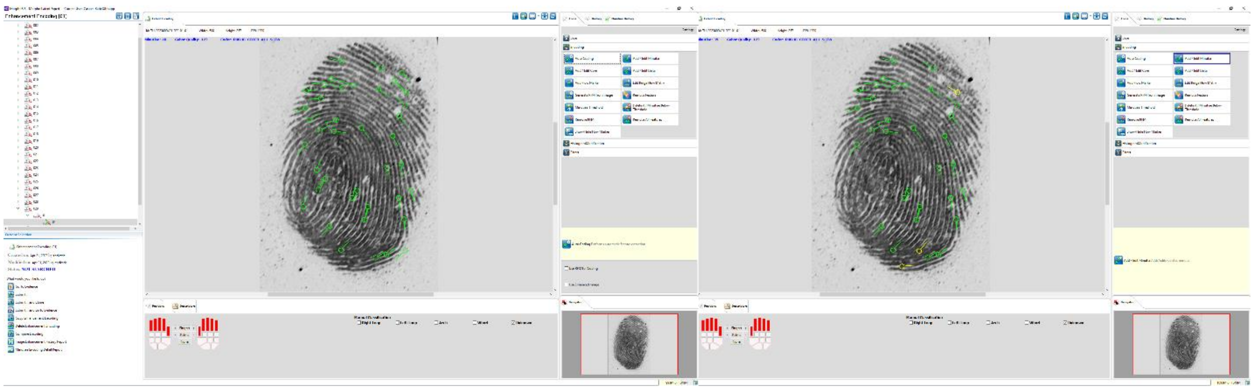

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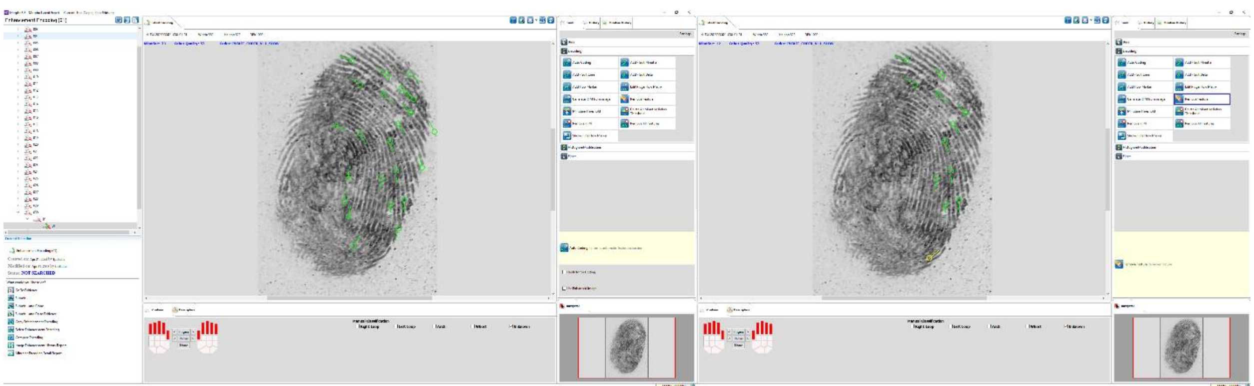

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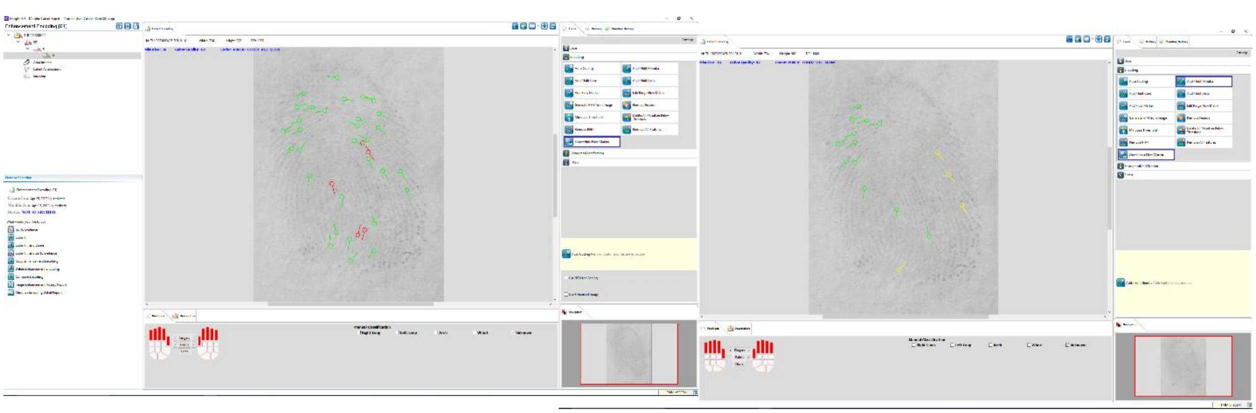
Before Clean-Up *After Clean-Up*



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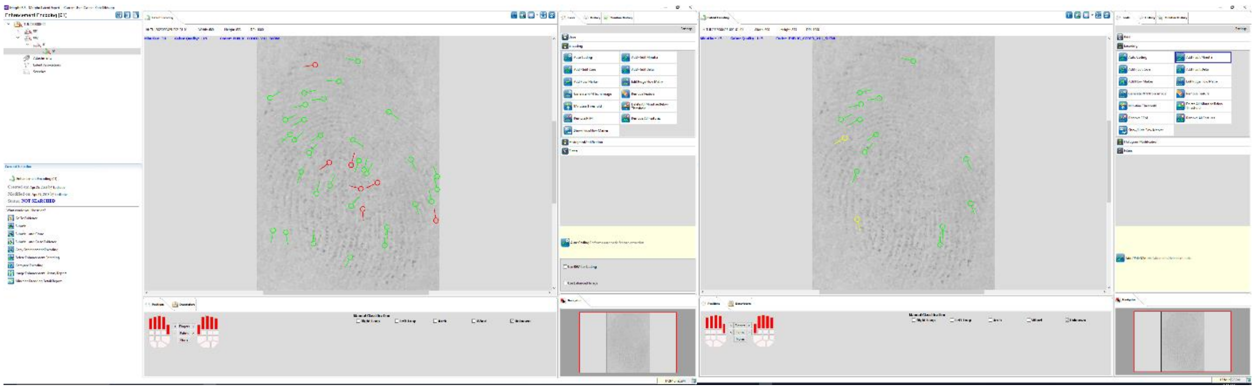

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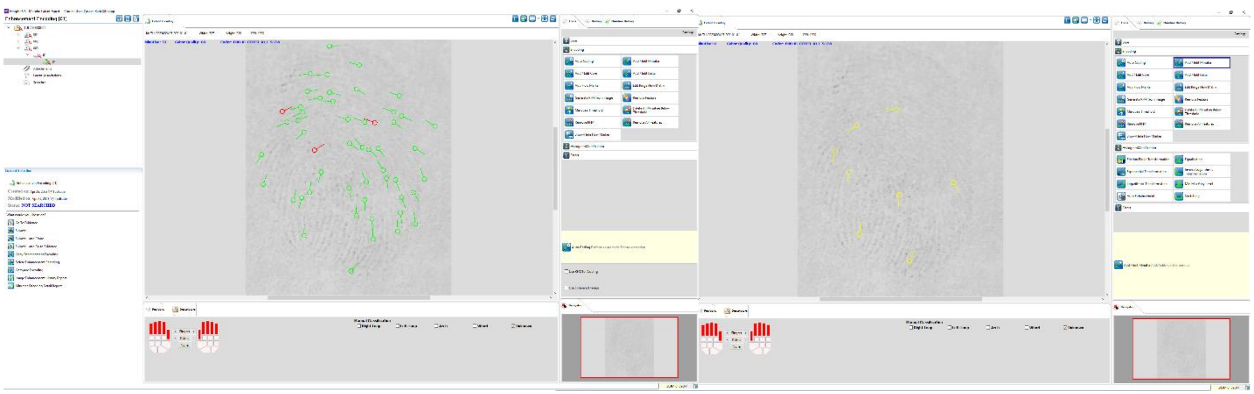

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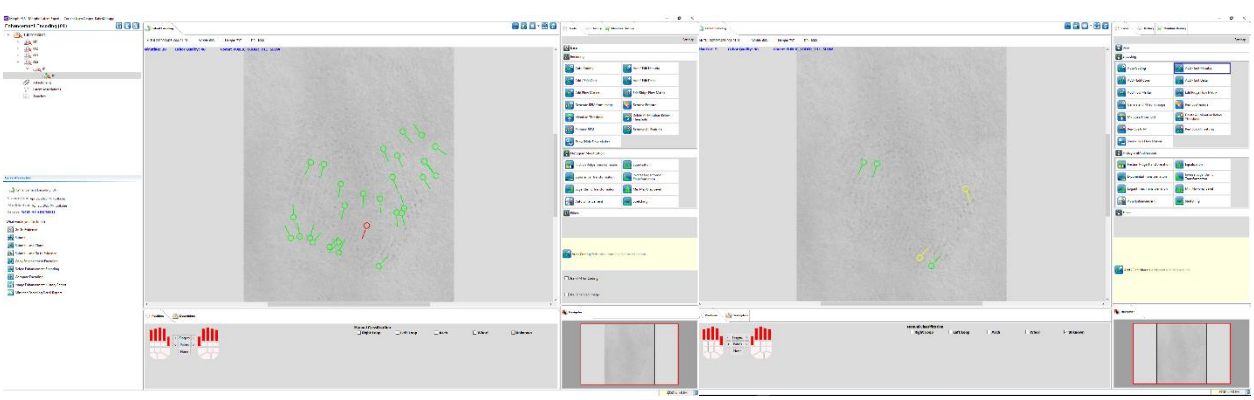

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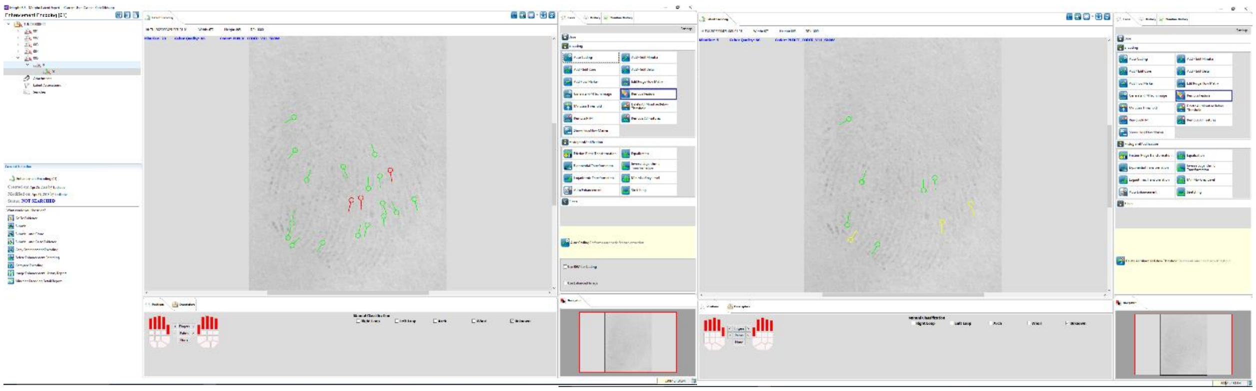

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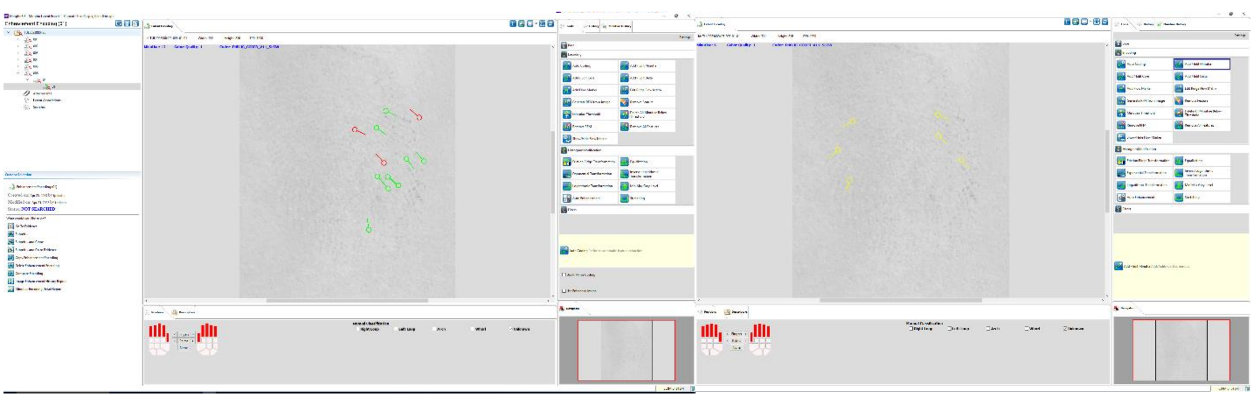

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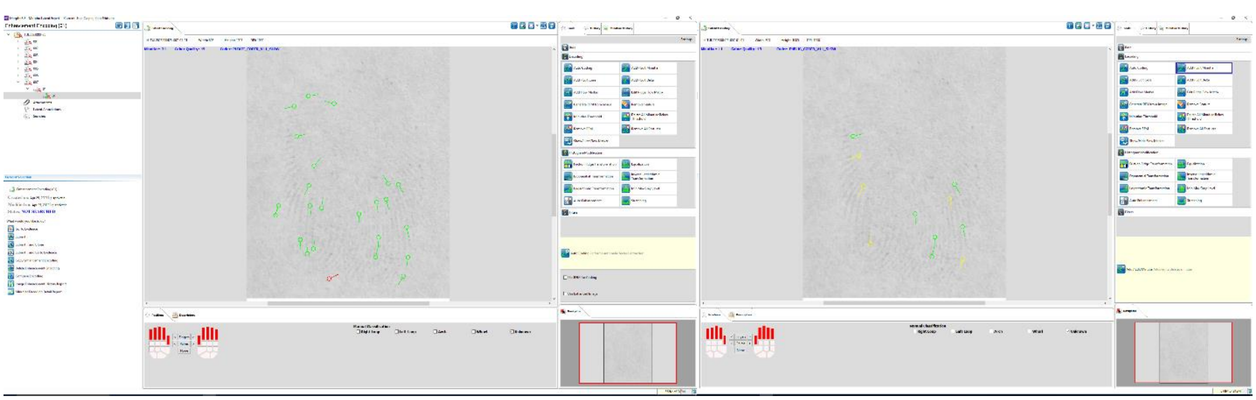

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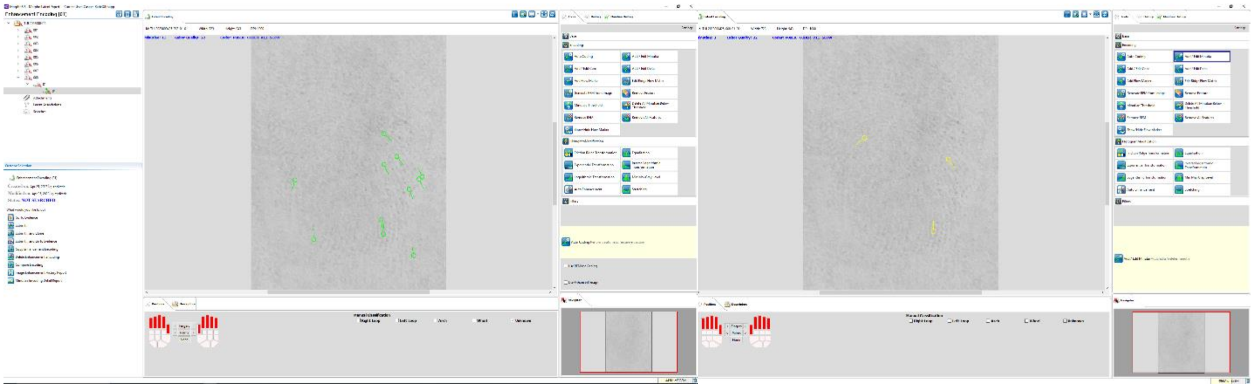

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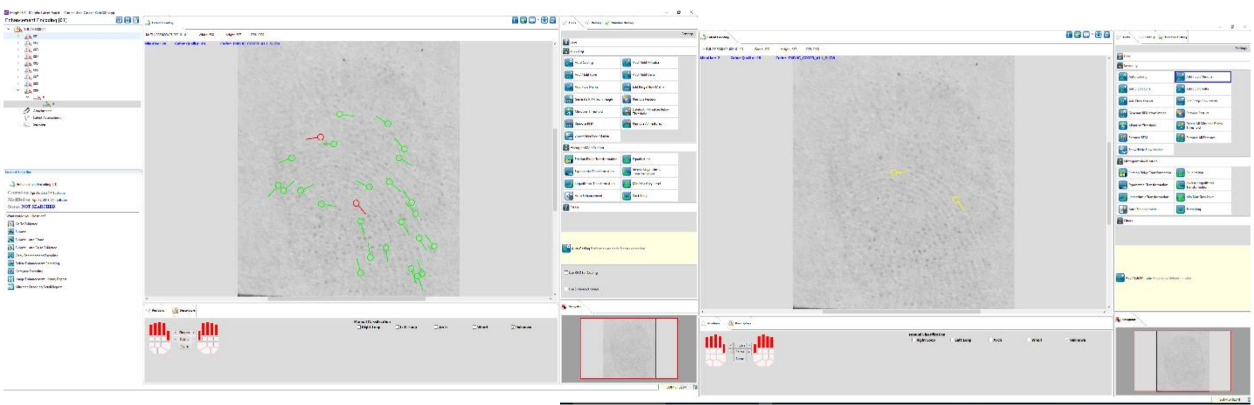

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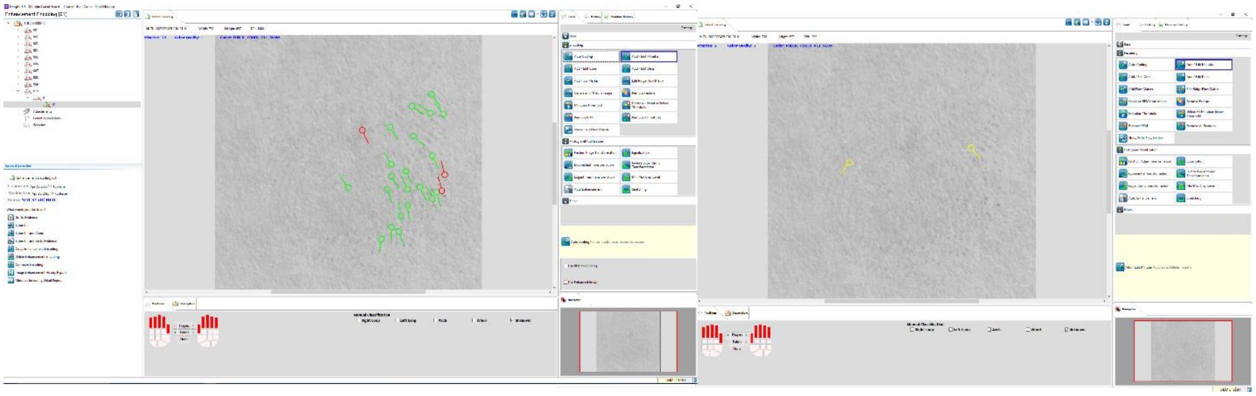

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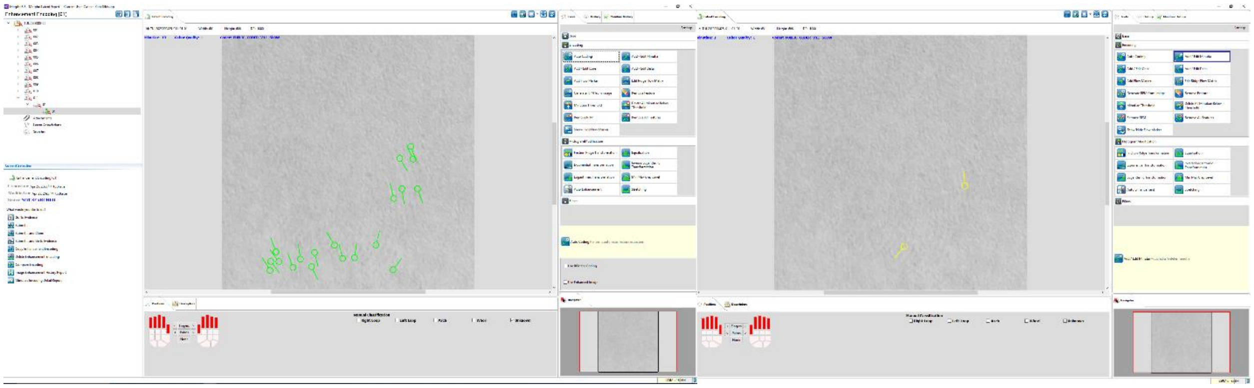

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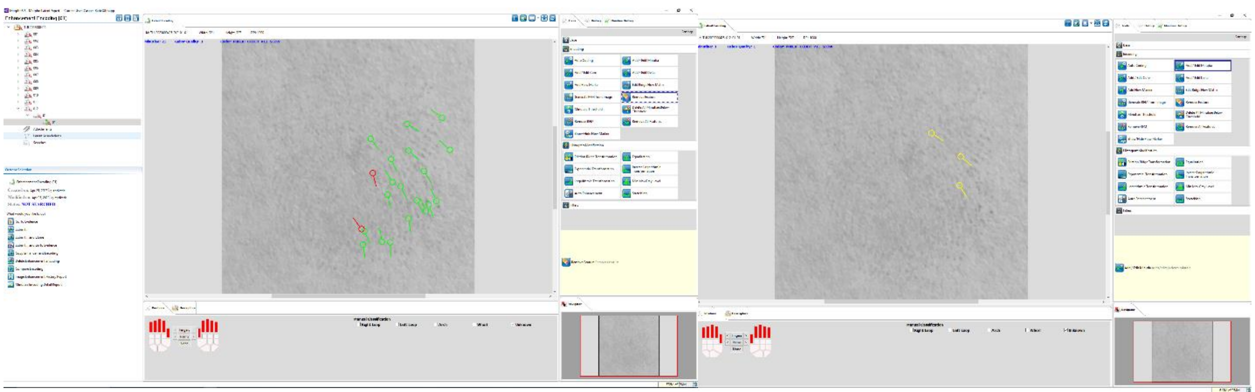

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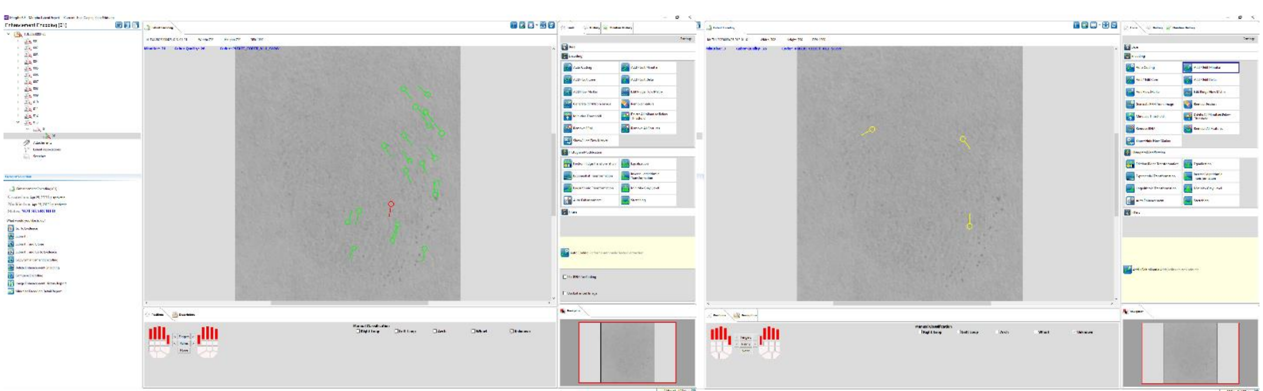

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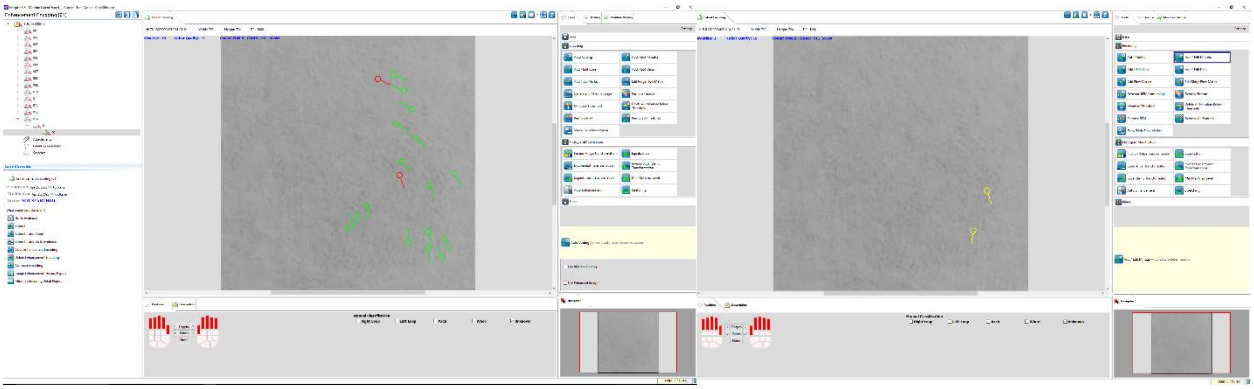

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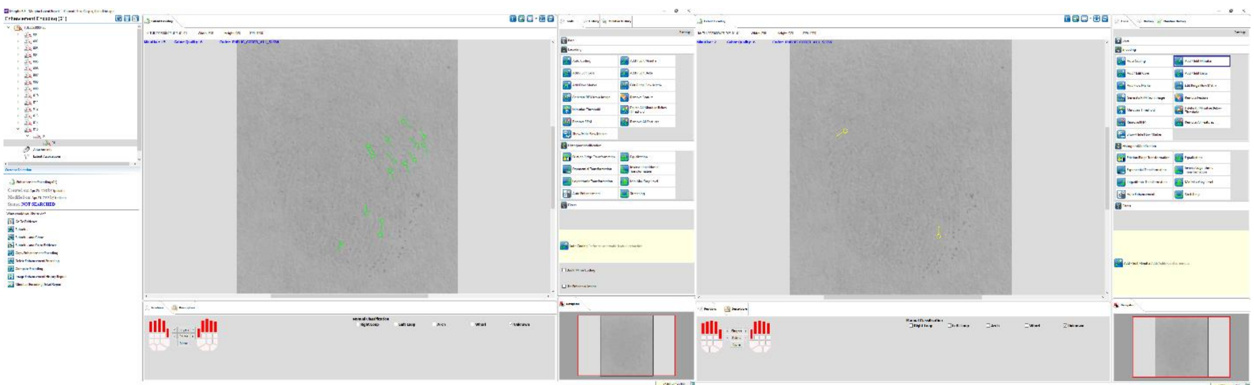

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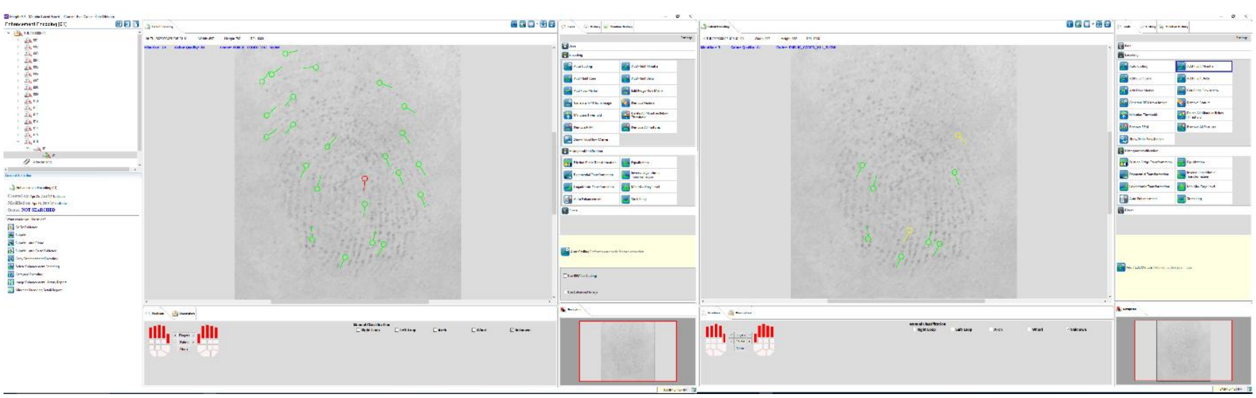

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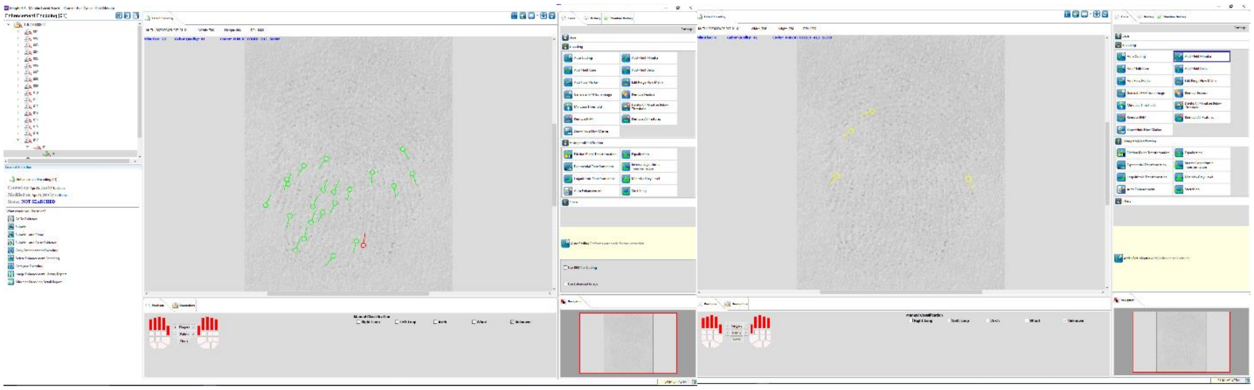

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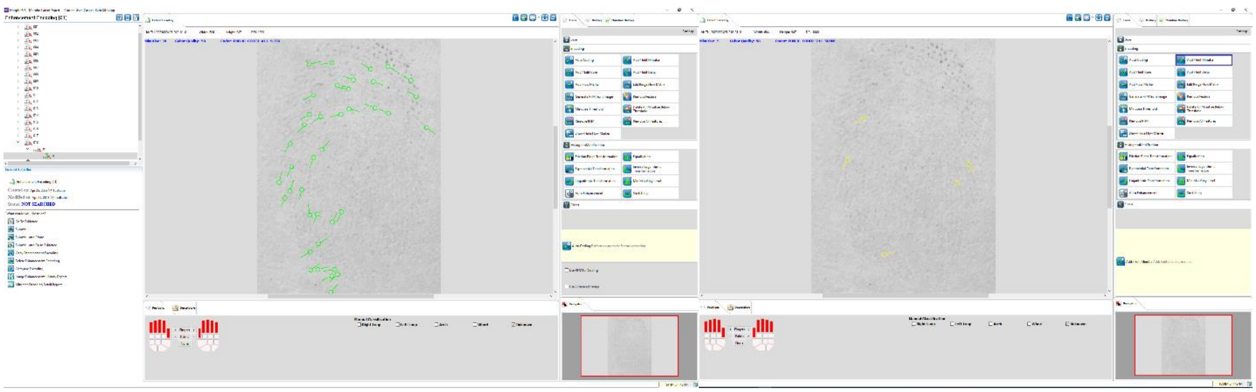

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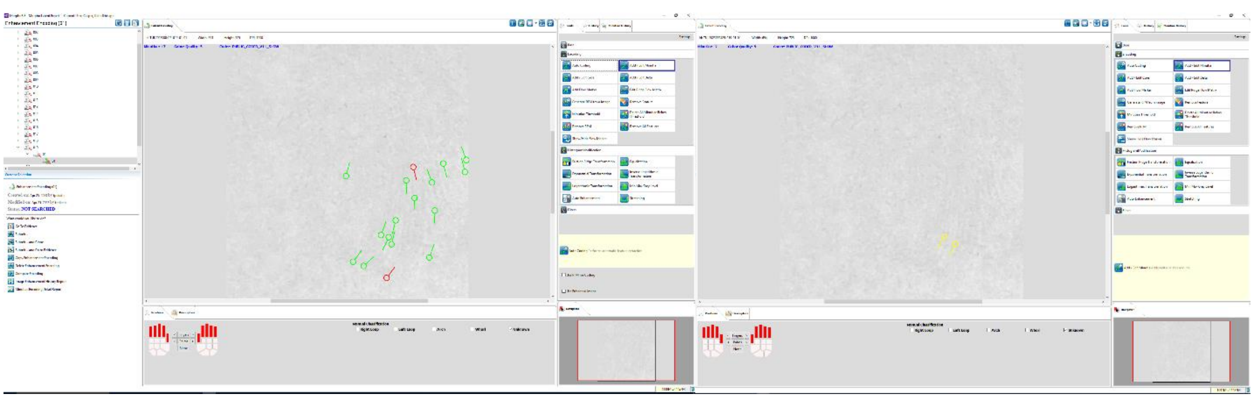

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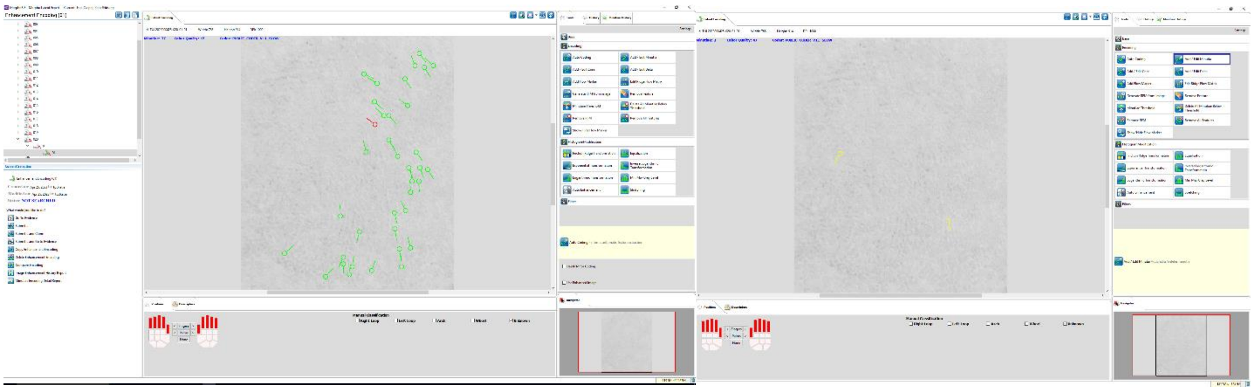

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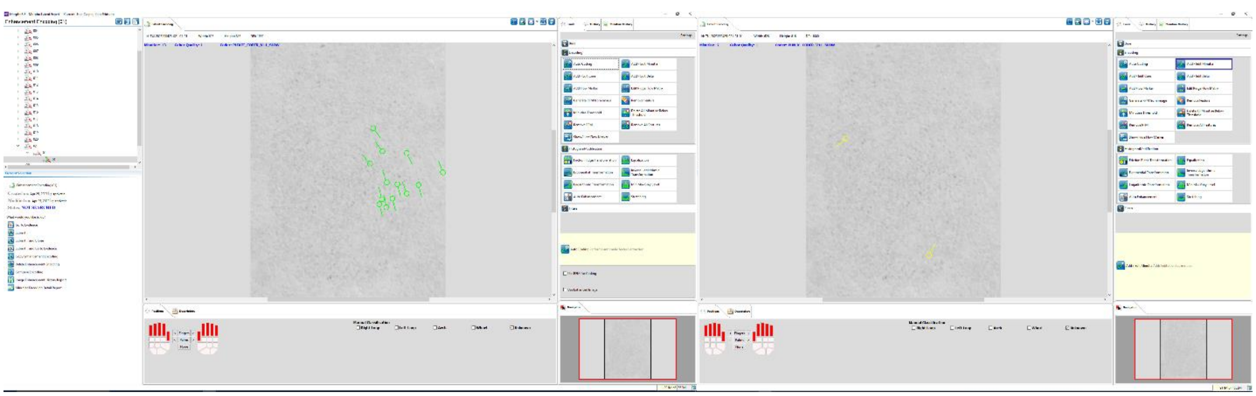

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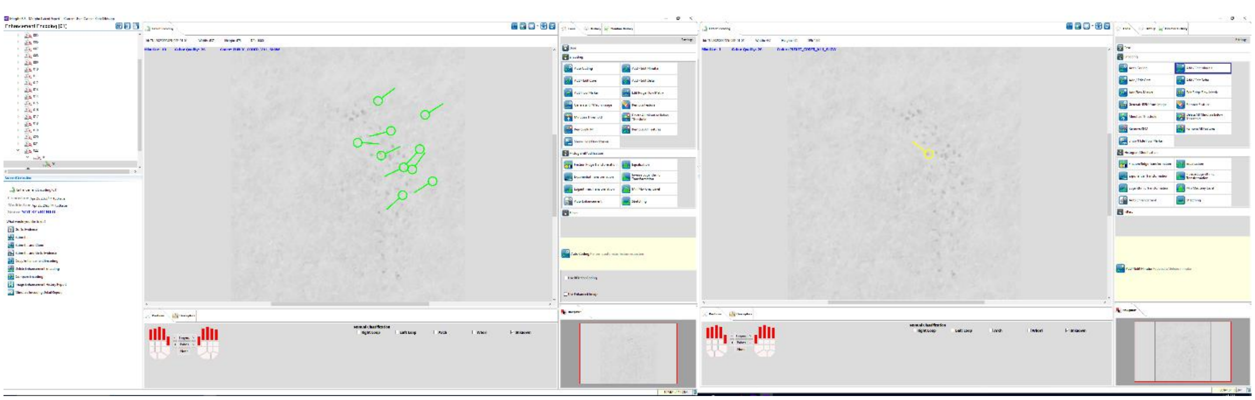

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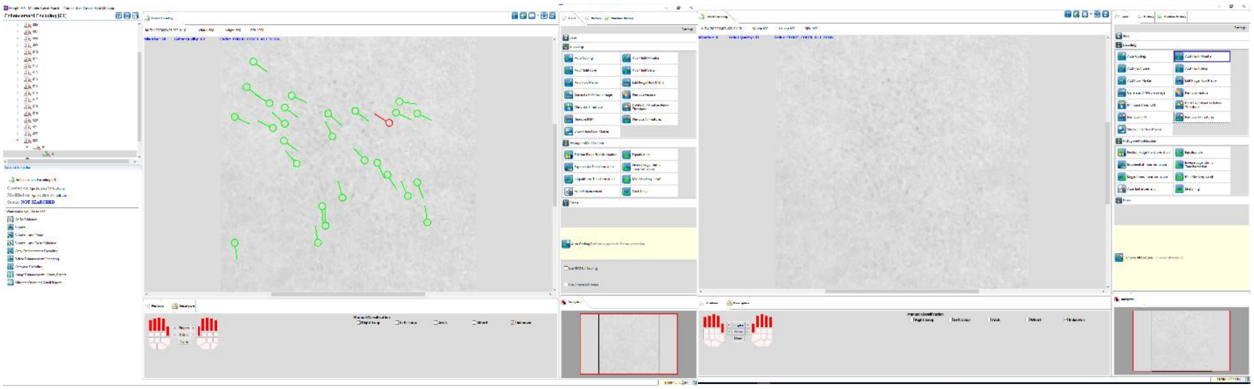
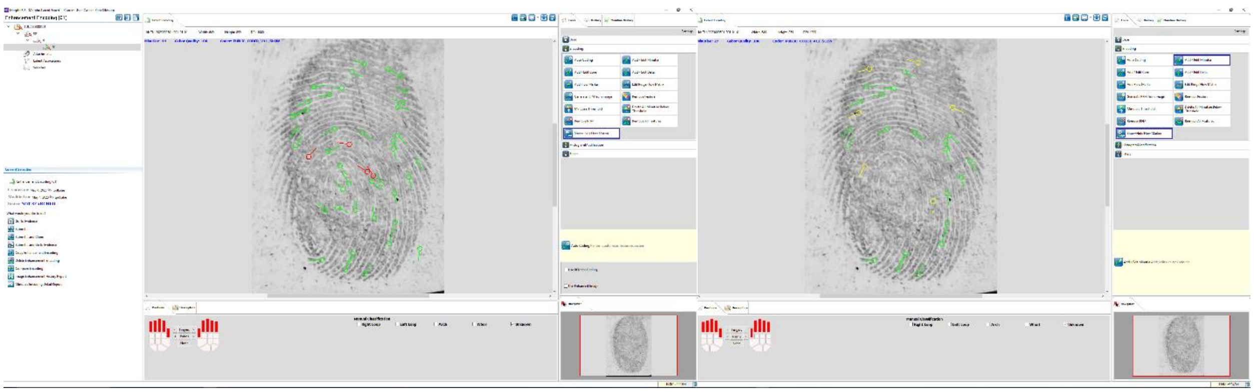


10A

50% Tile

Before Clean-Up *After Clean-Up*



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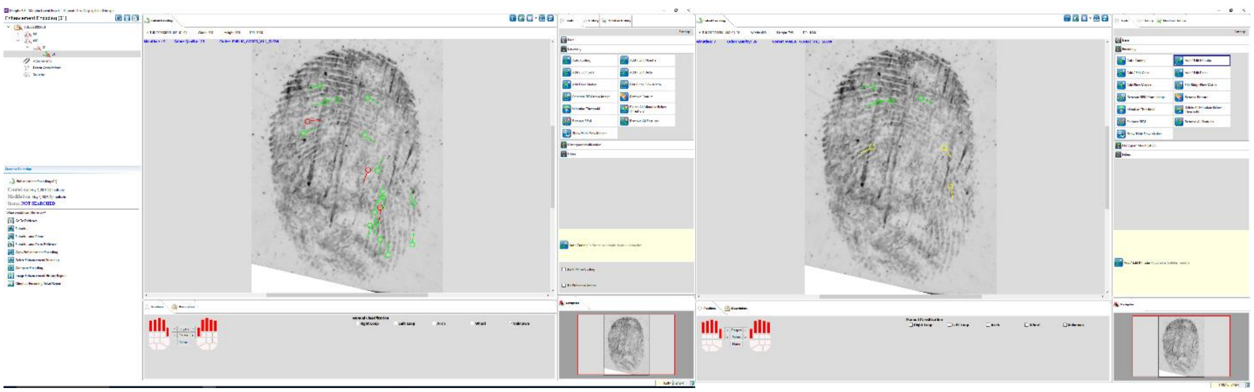

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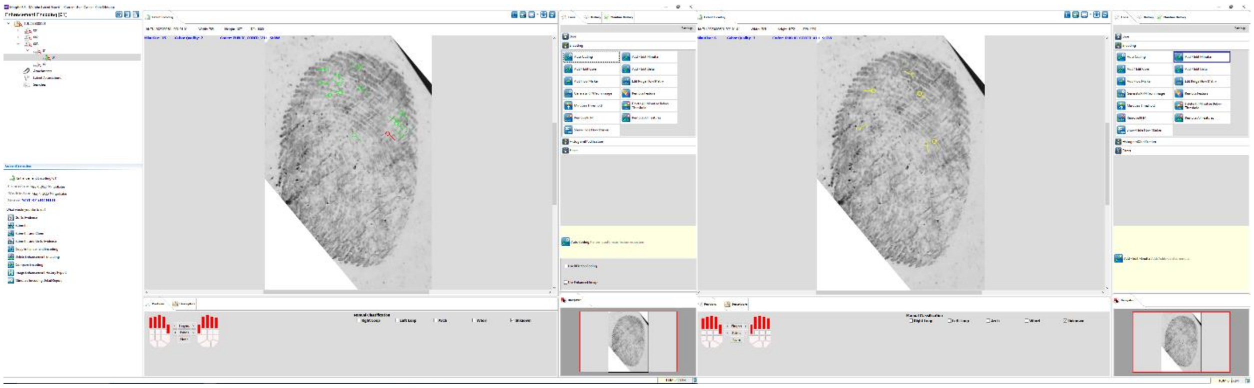

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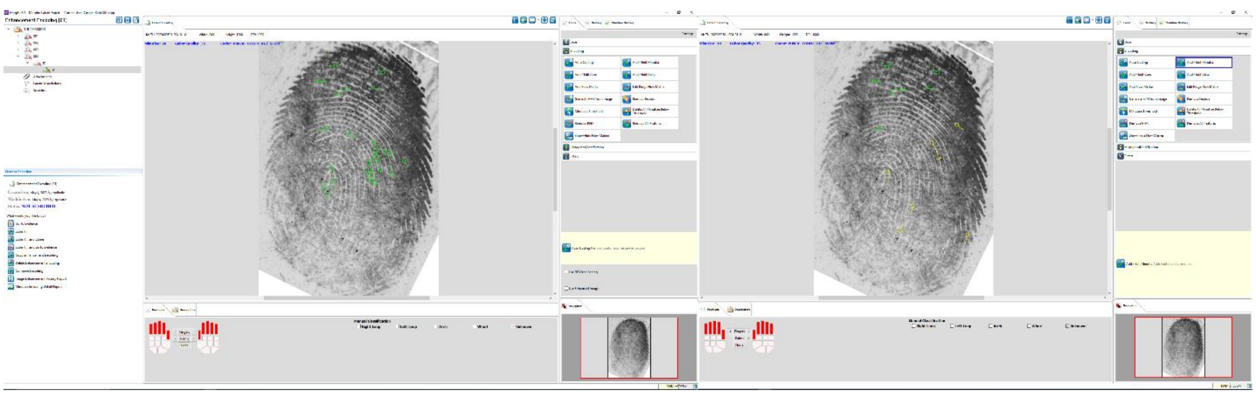

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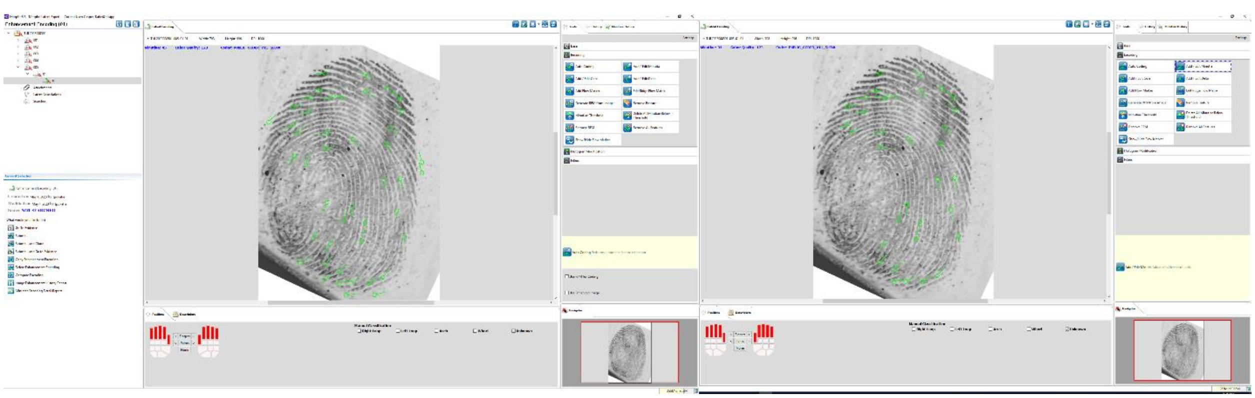

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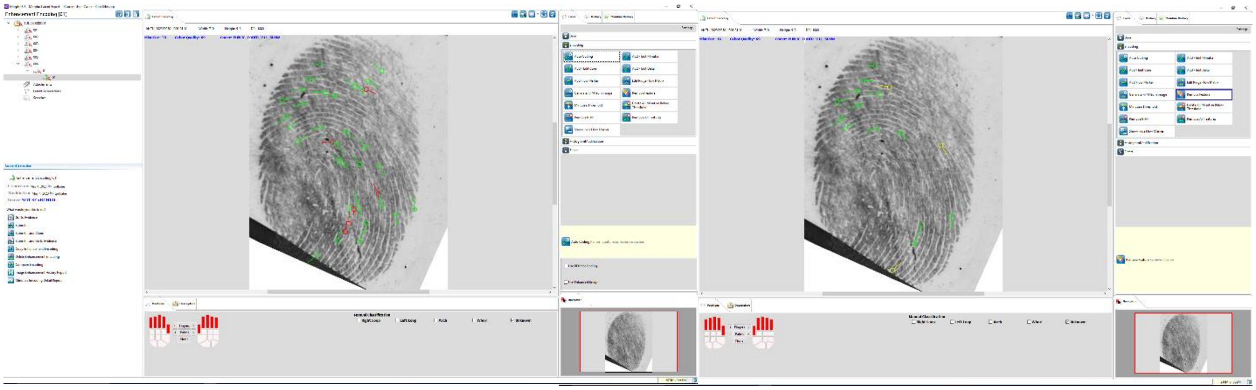

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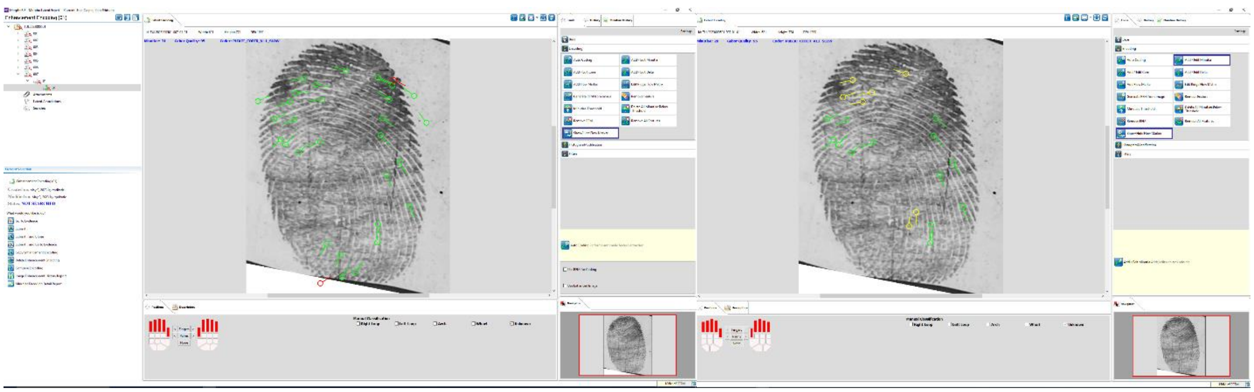

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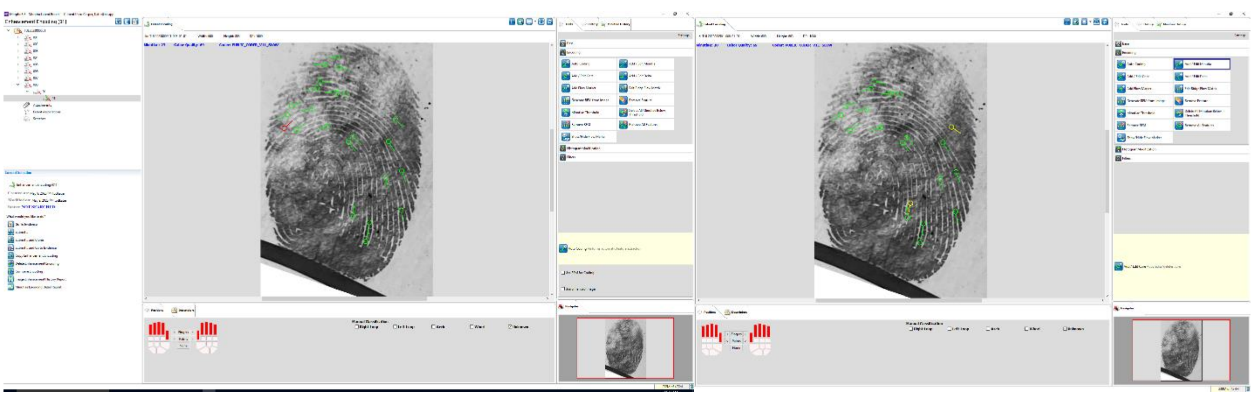

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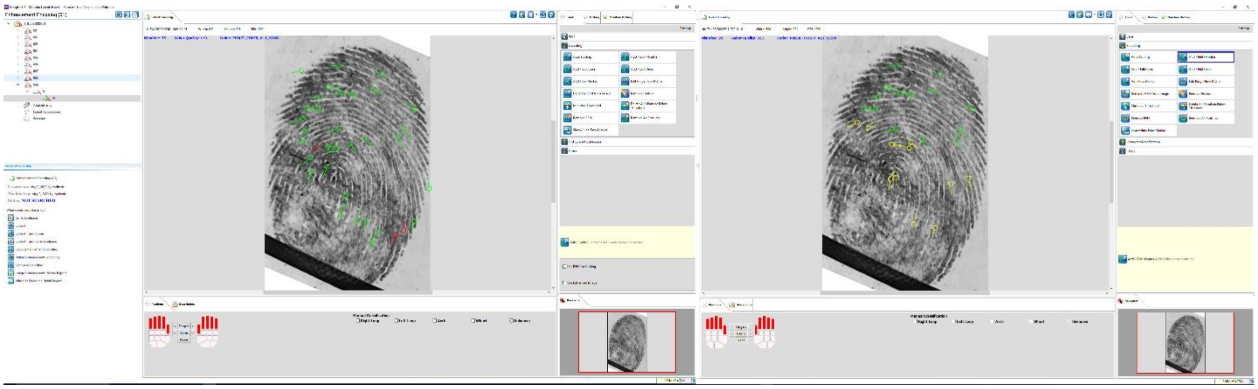

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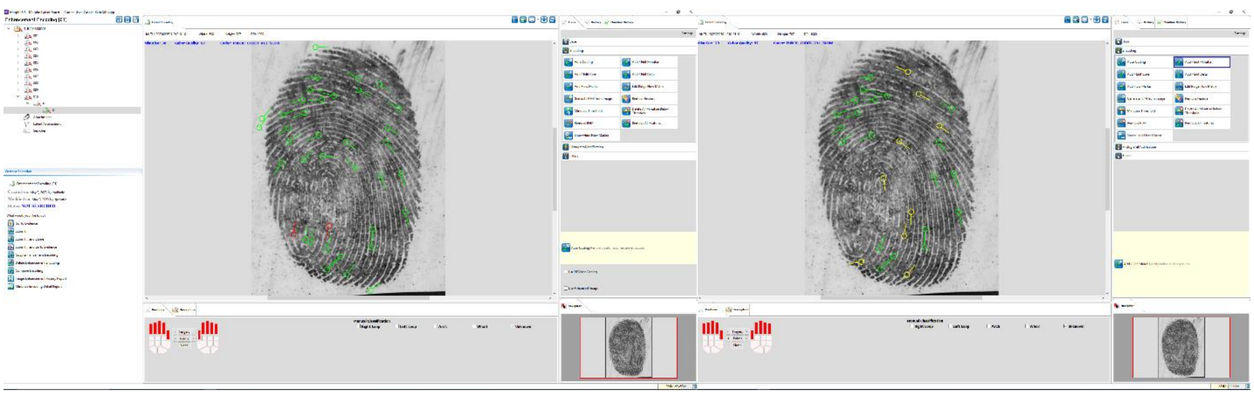

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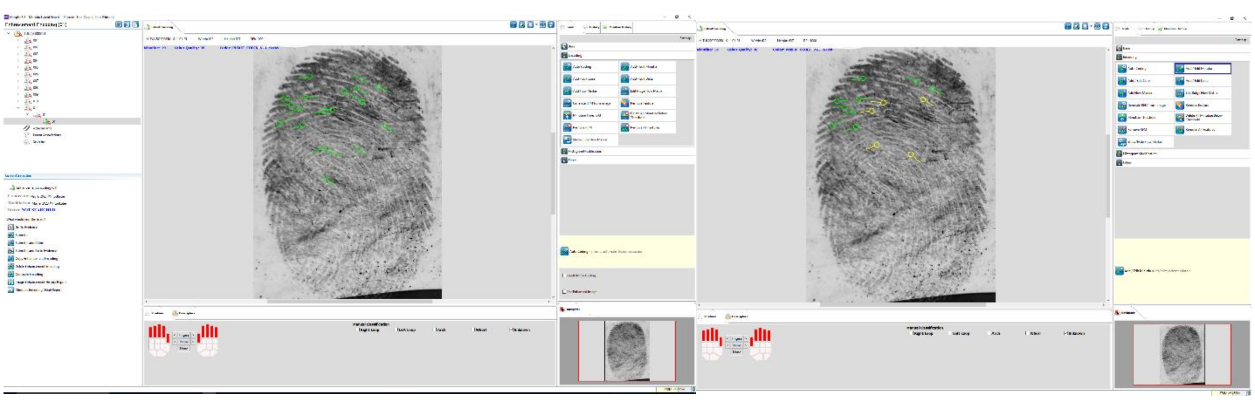

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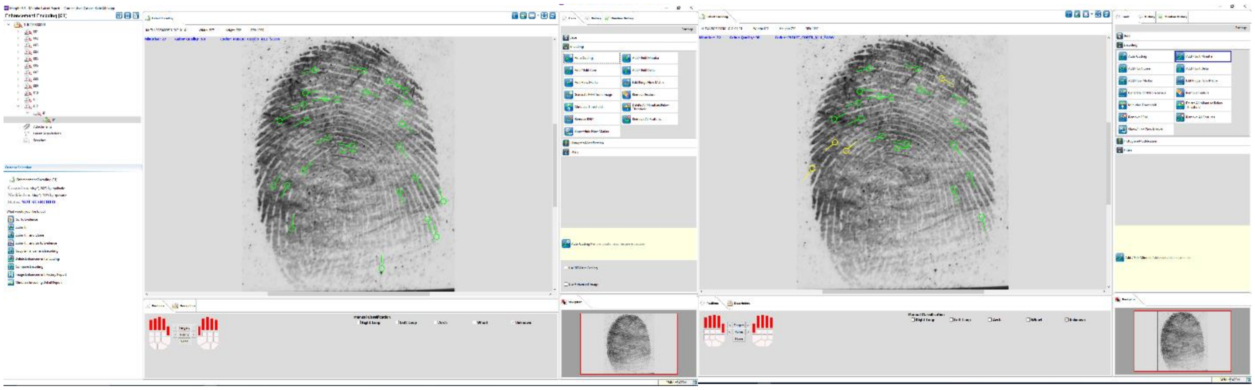

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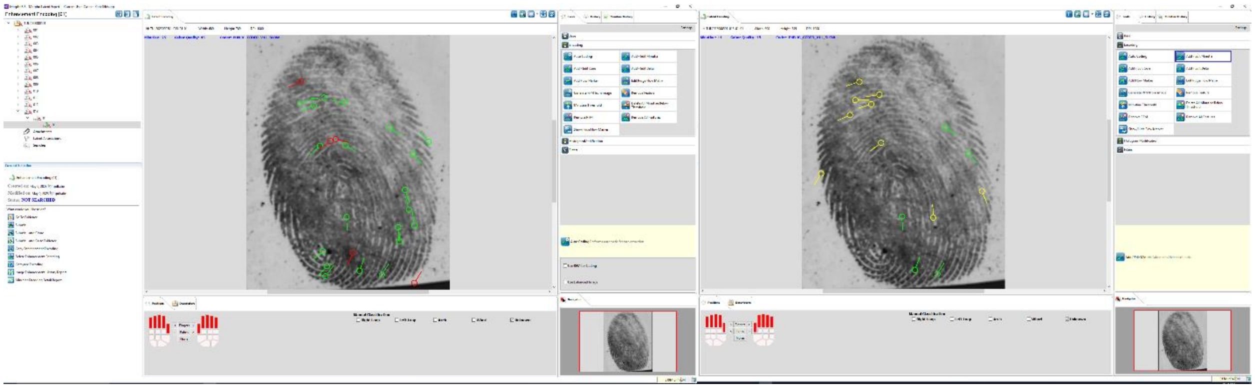

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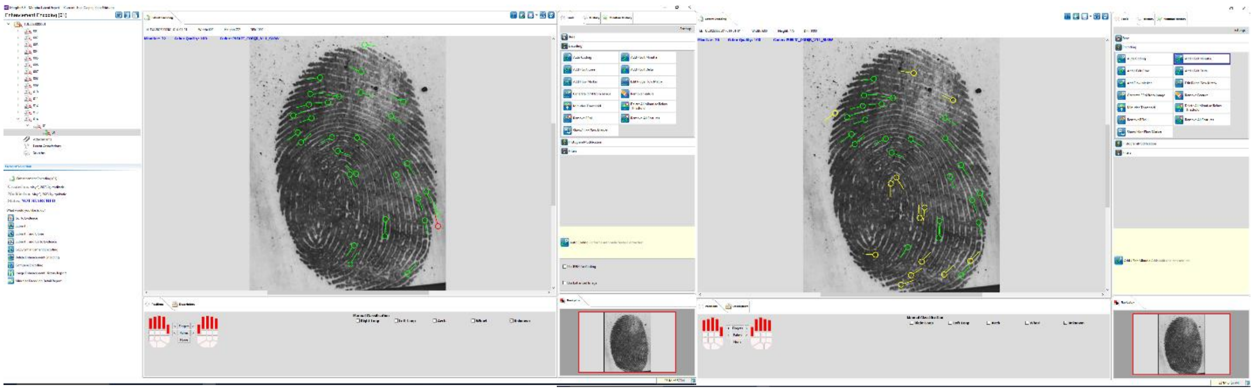

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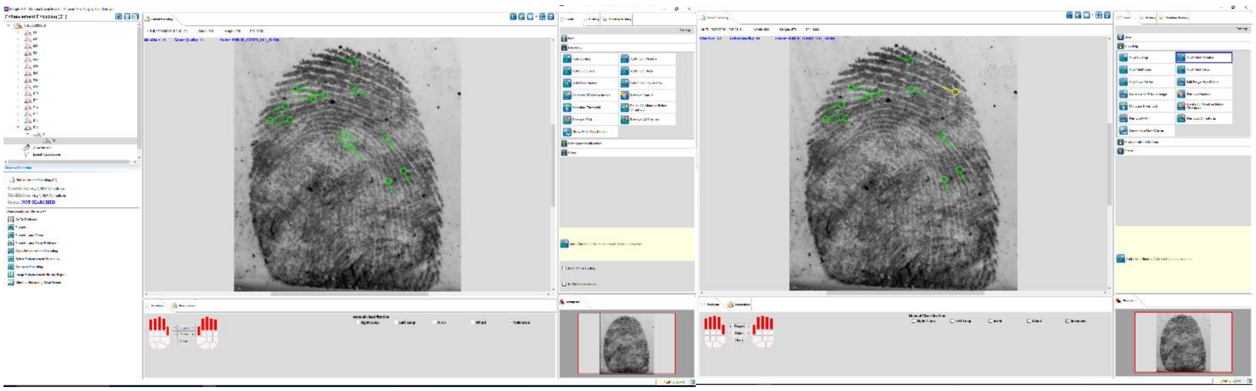

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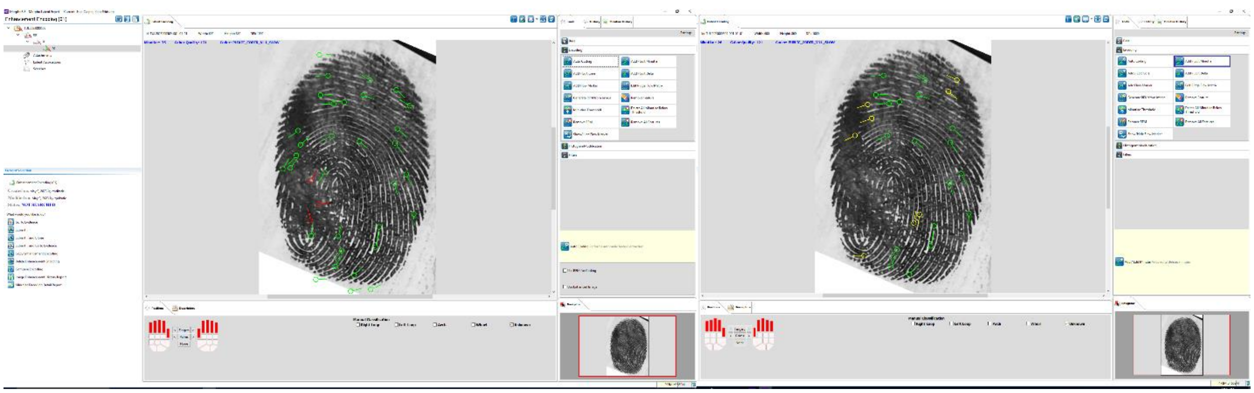

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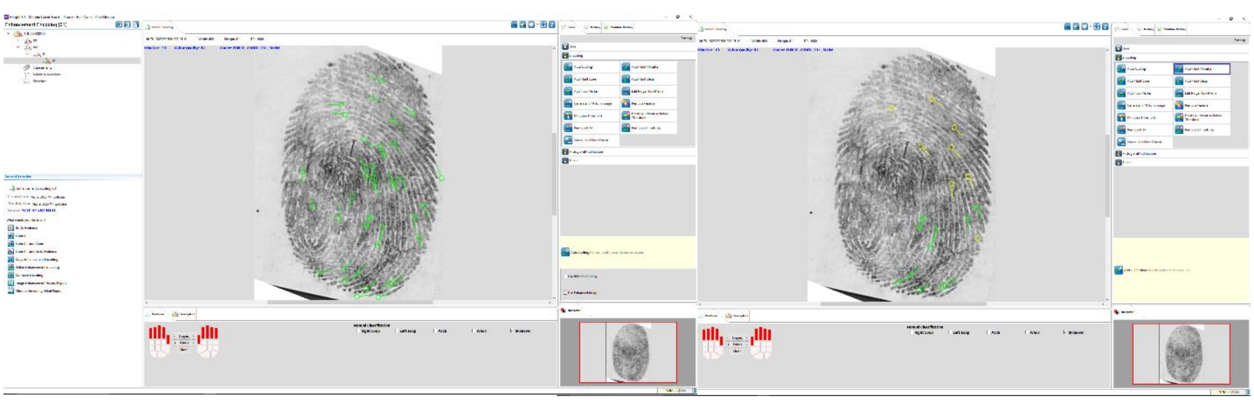

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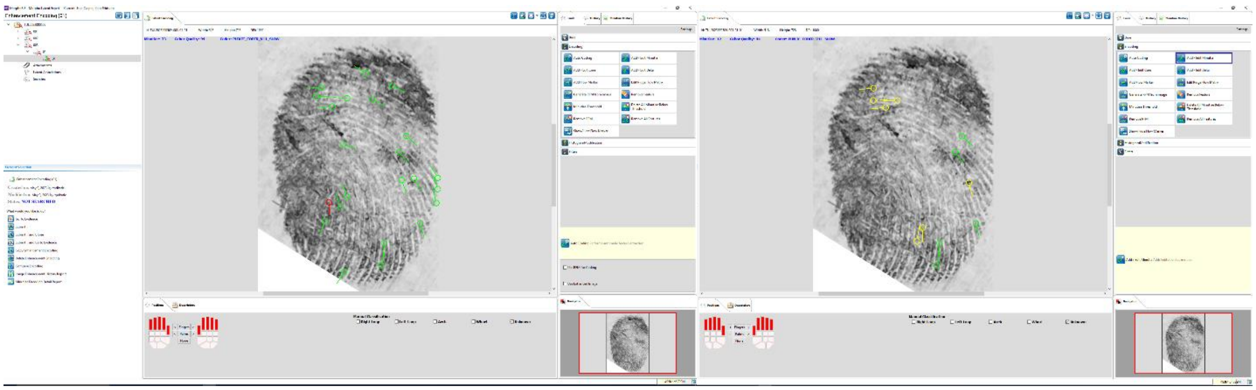

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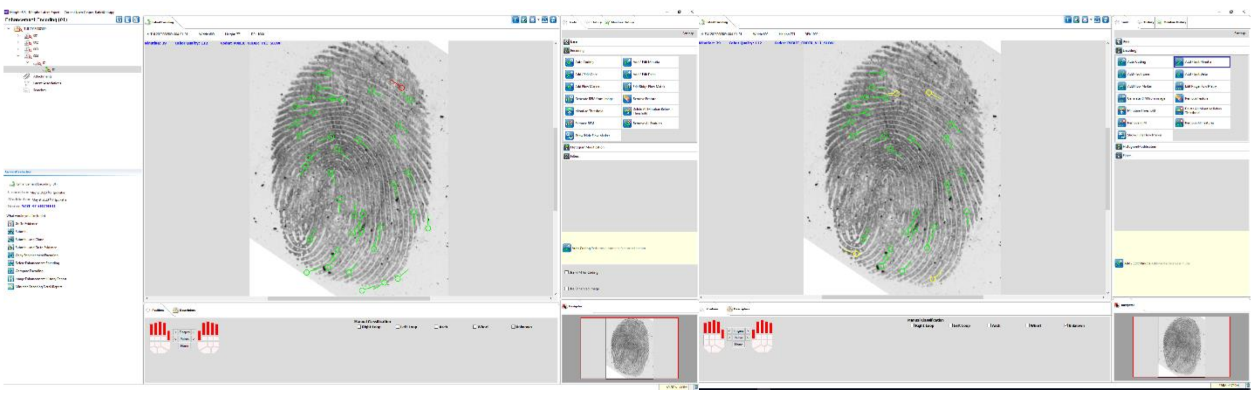

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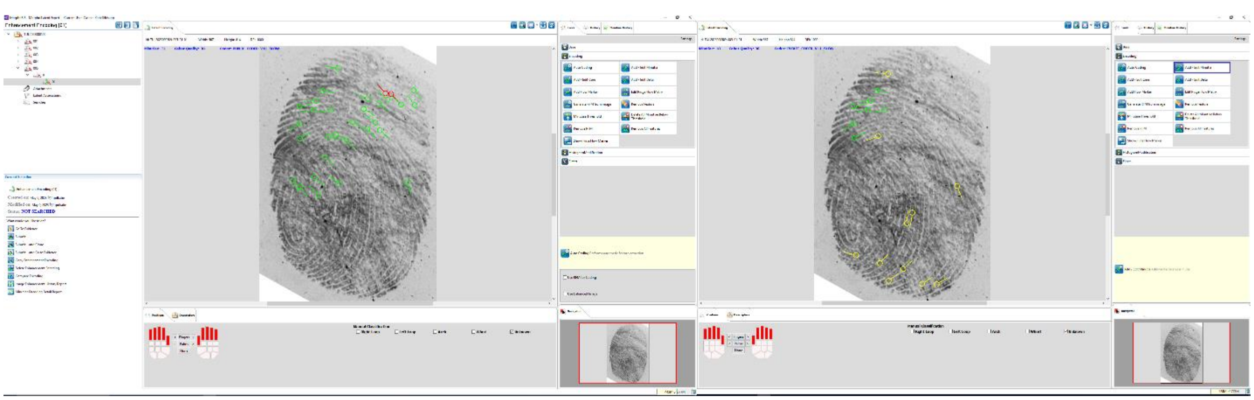

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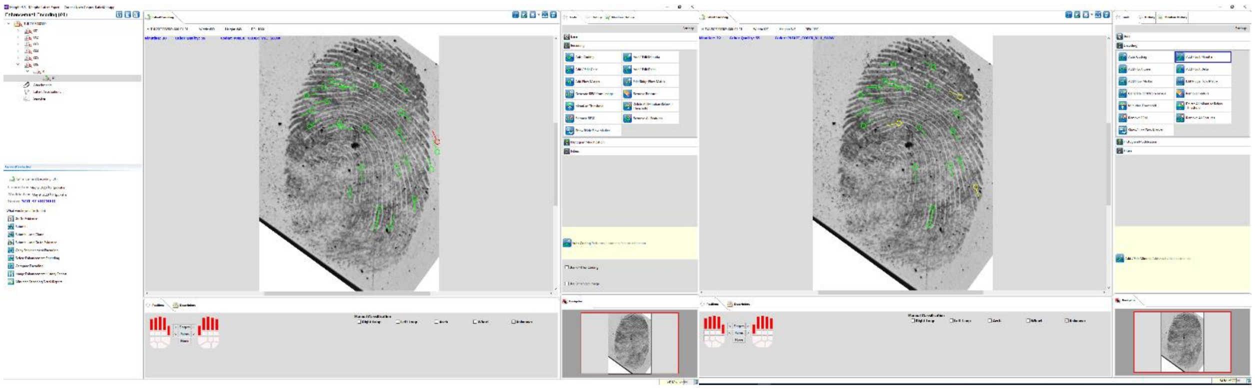

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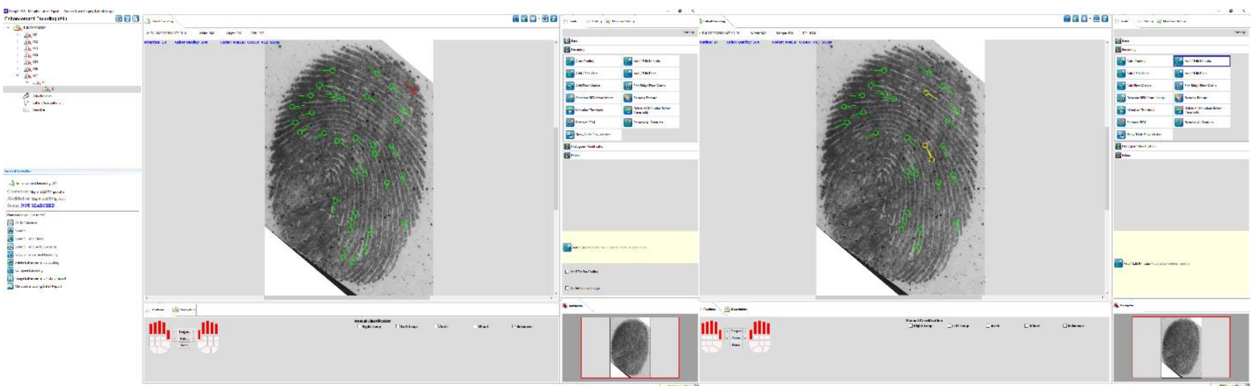

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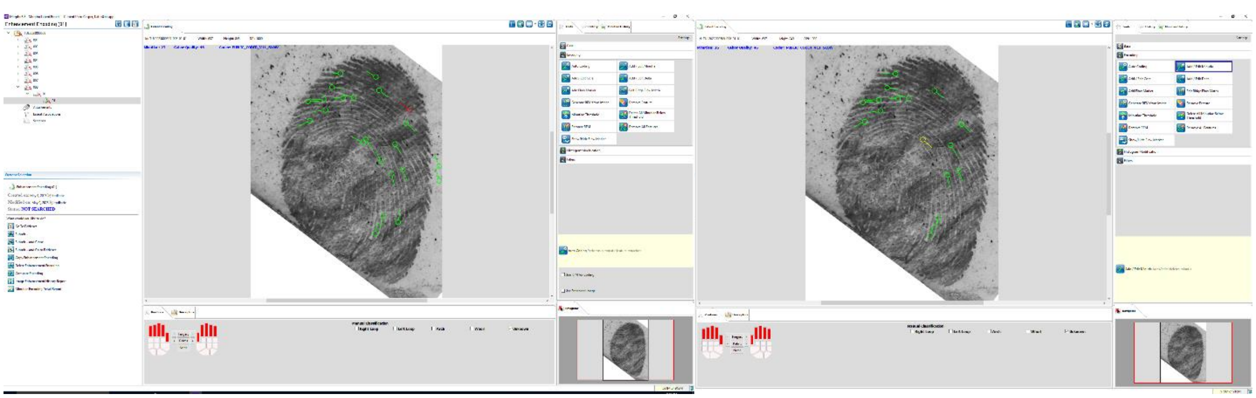

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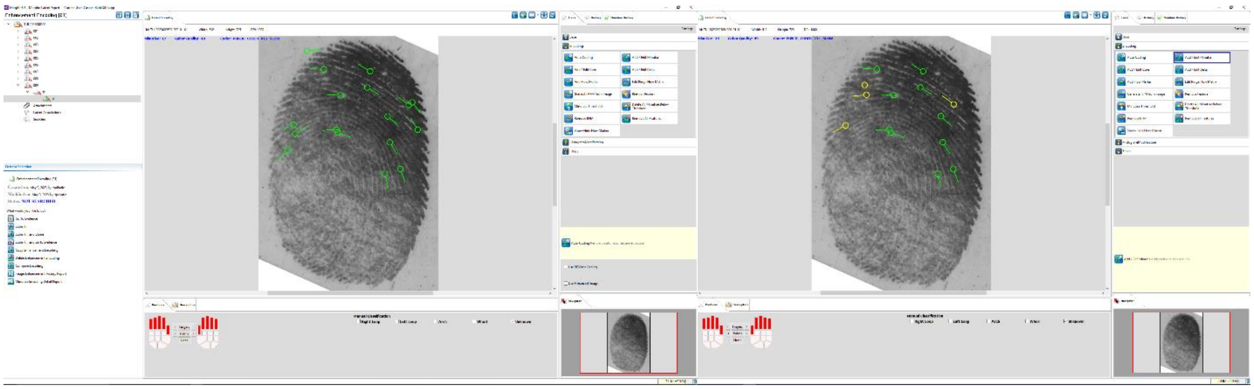

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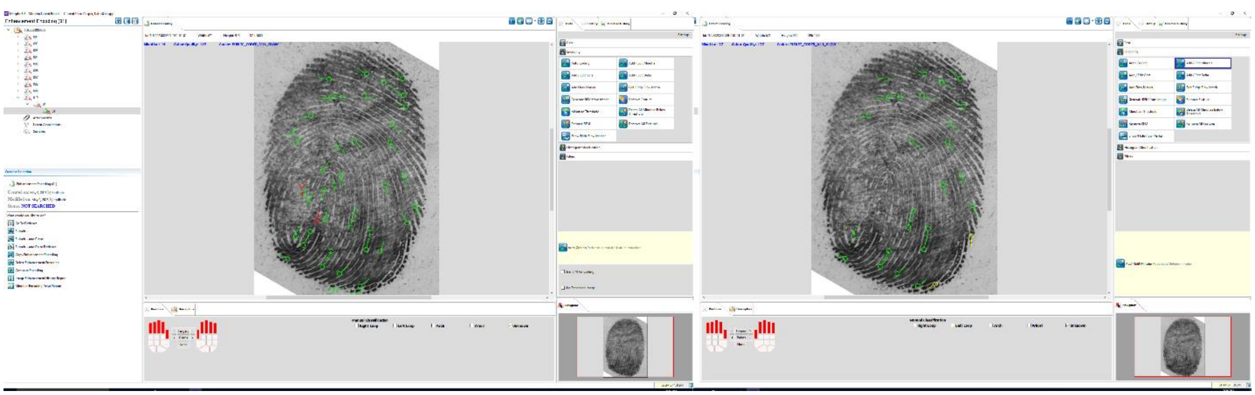

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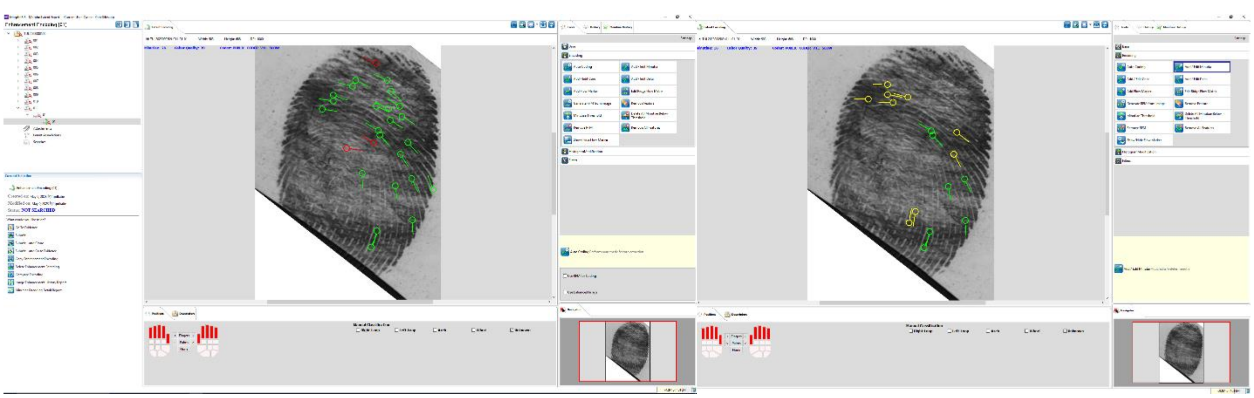

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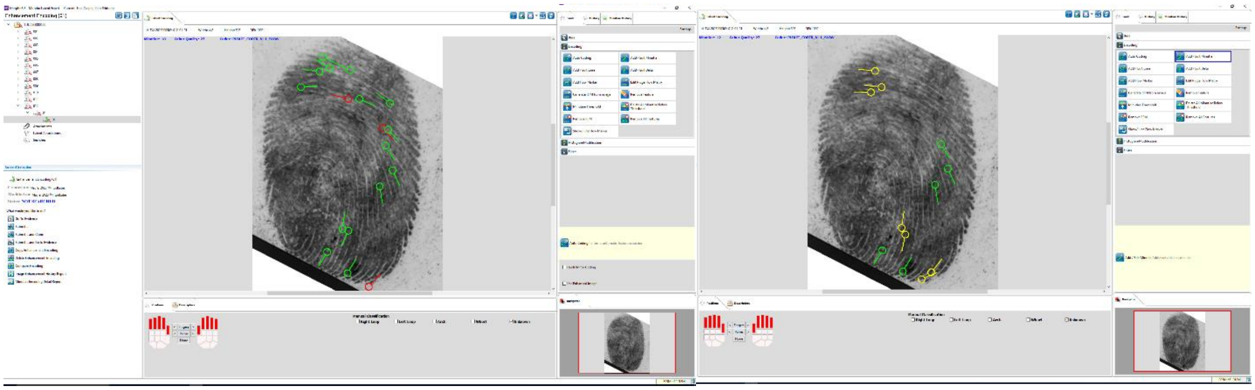

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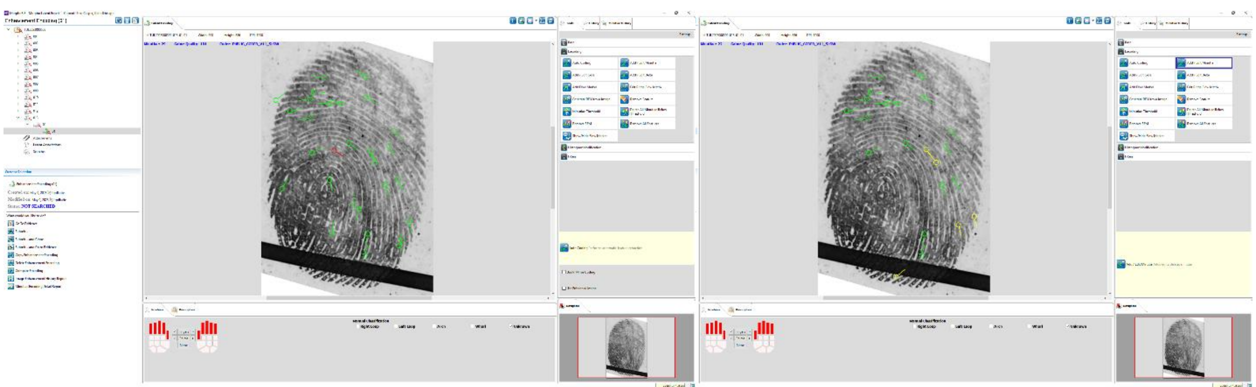

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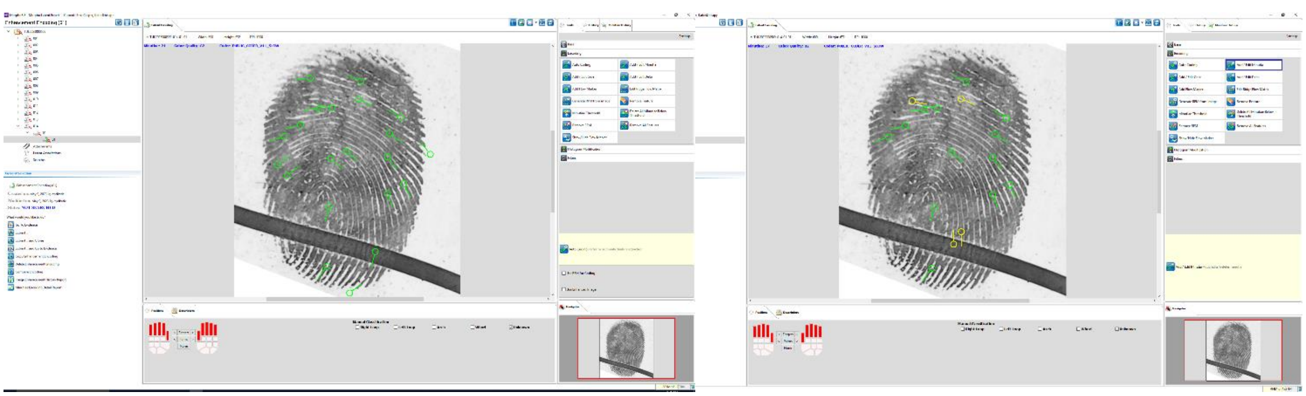

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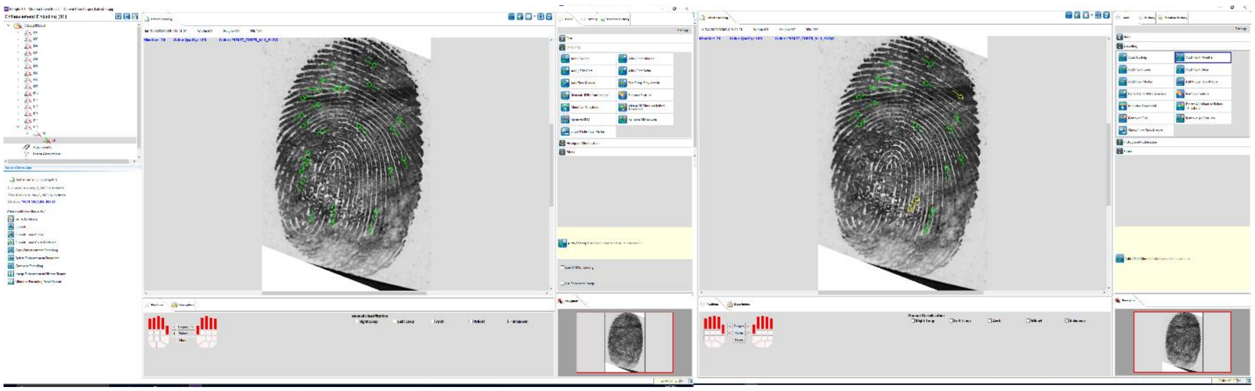

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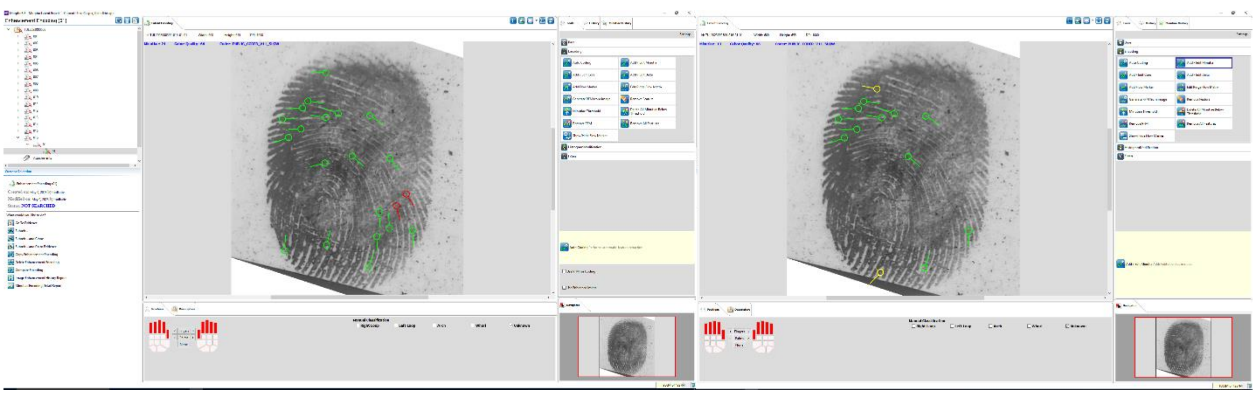

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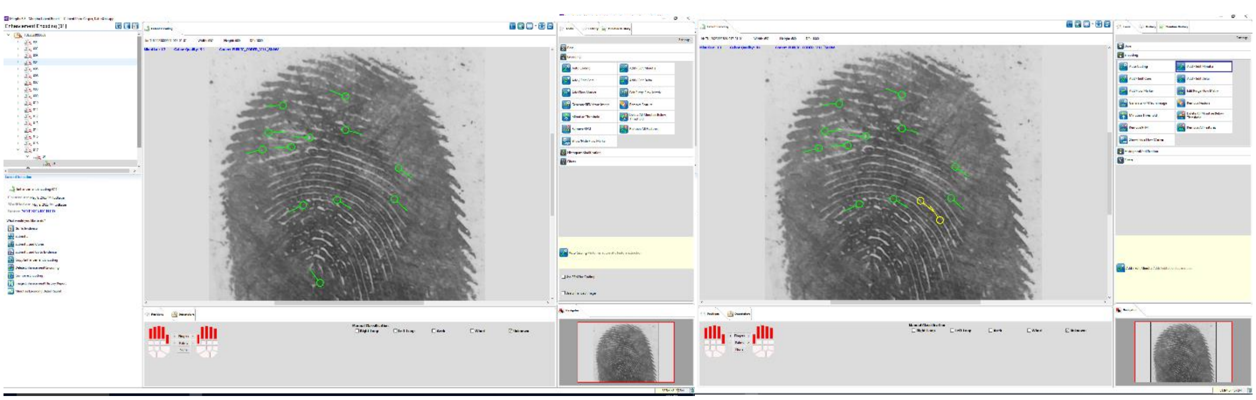

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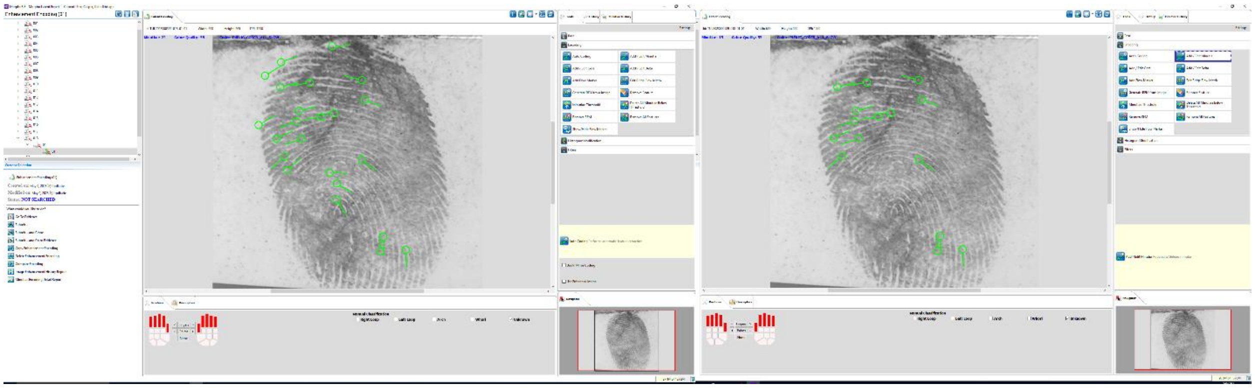

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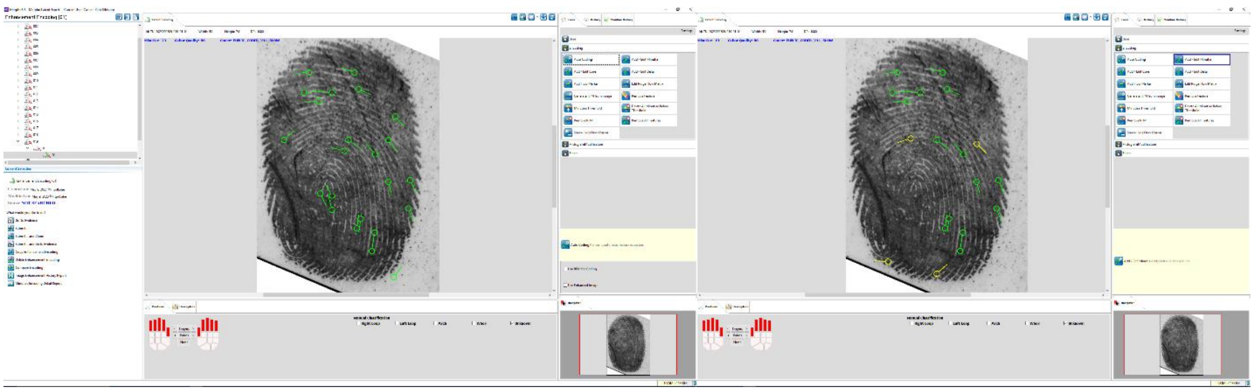

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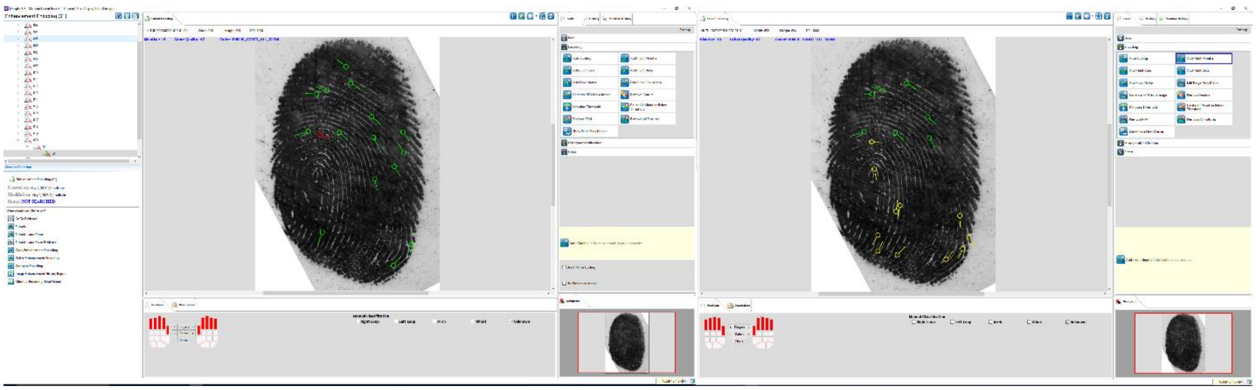

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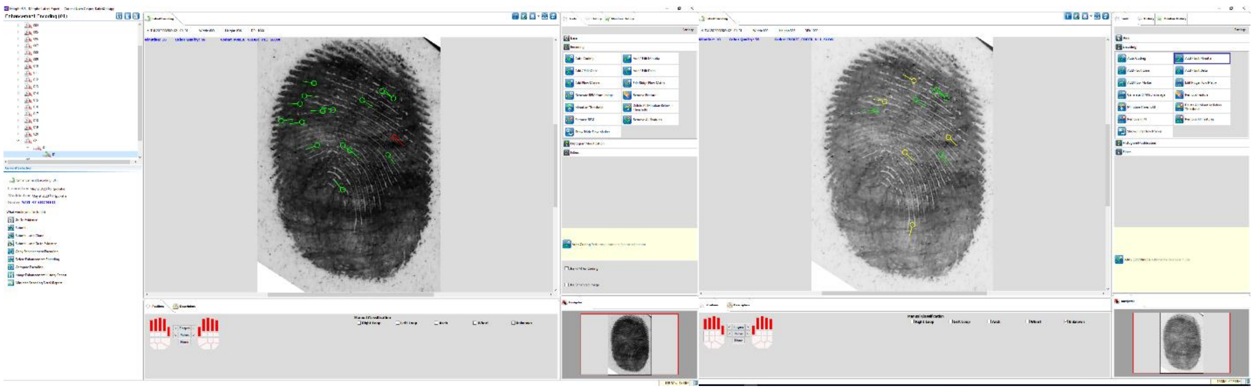

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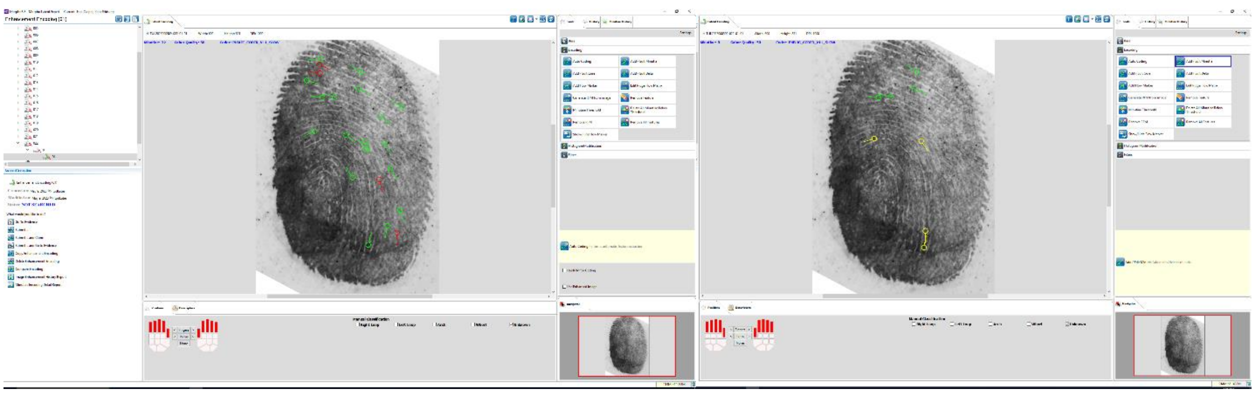

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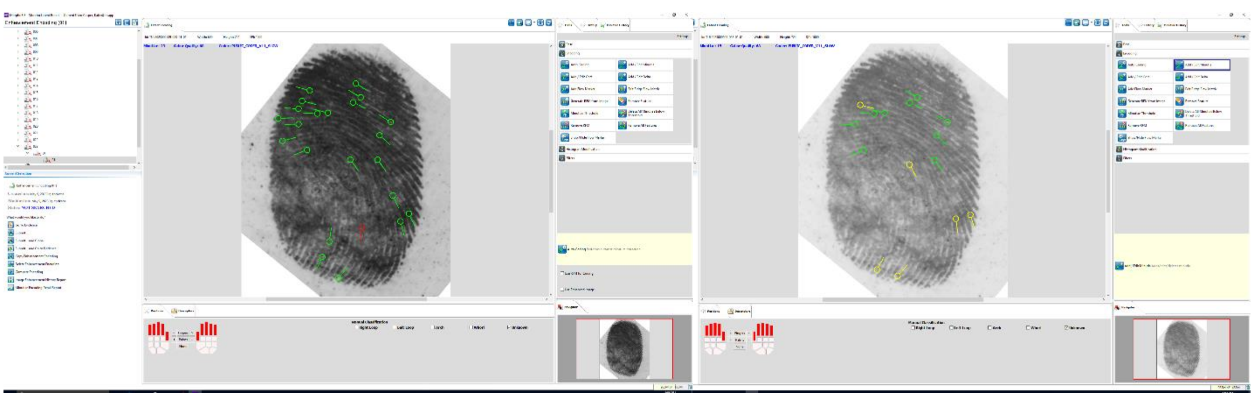

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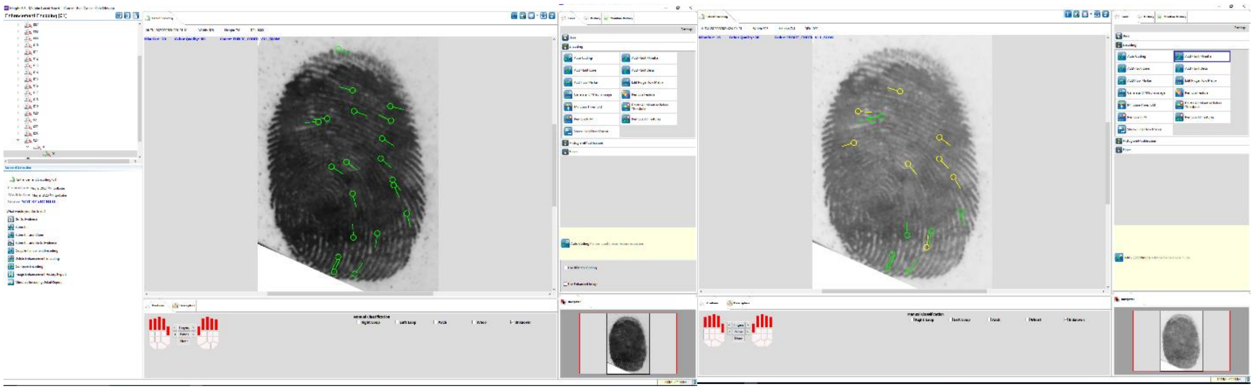

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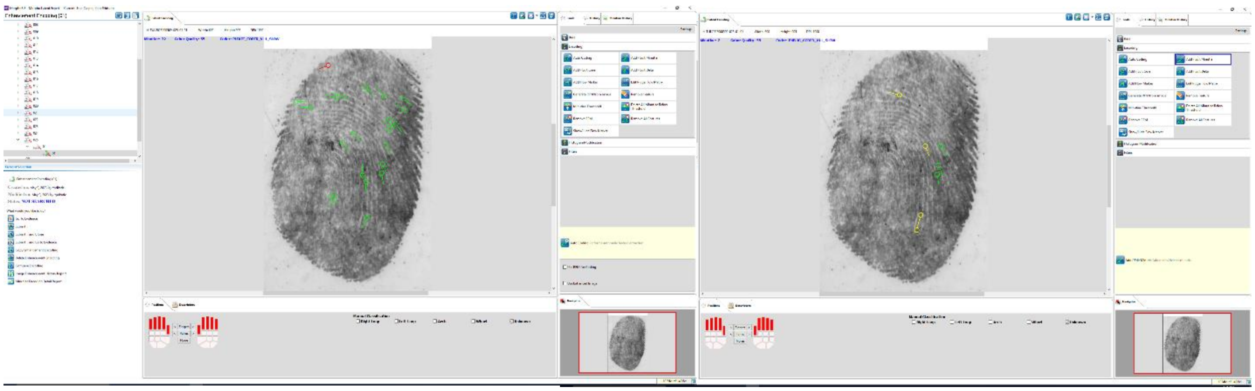

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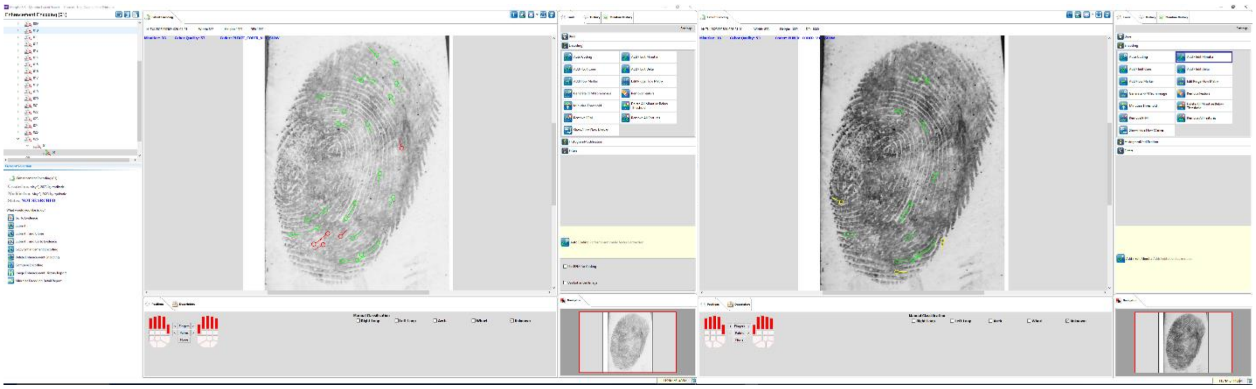

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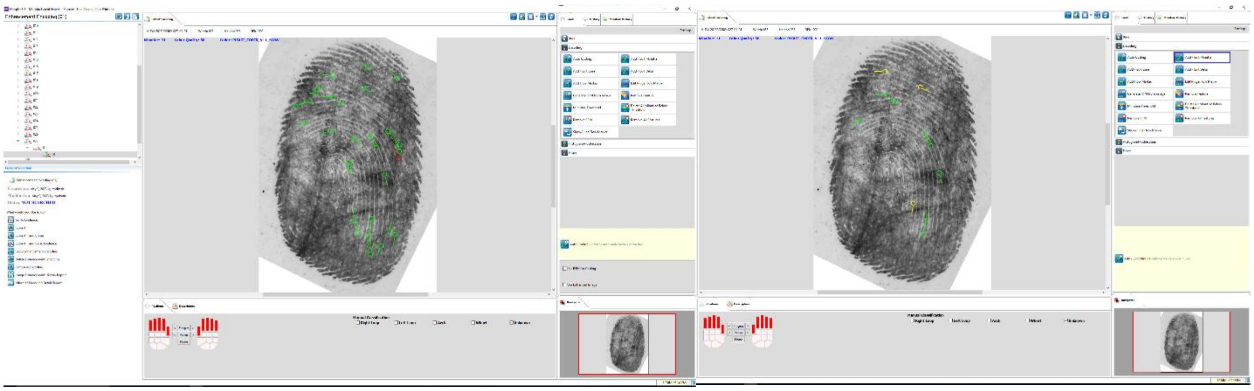

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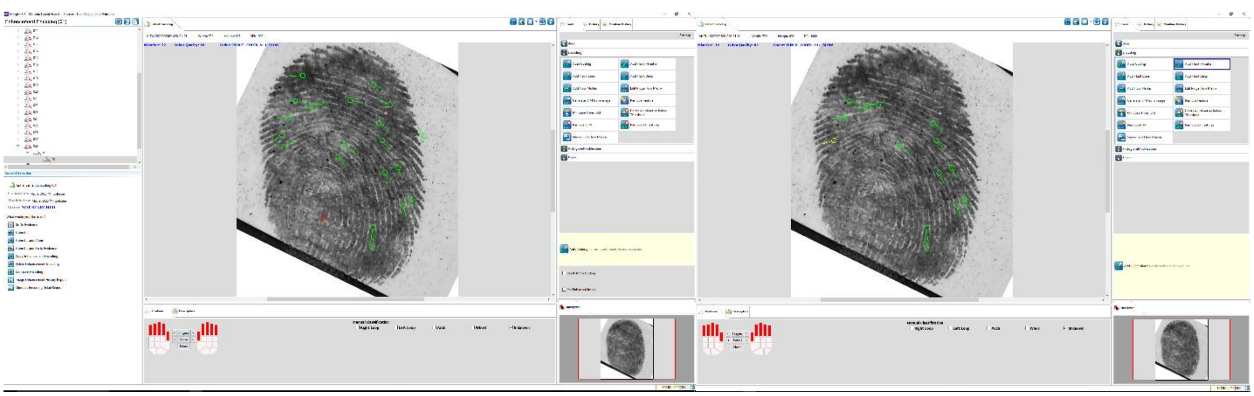

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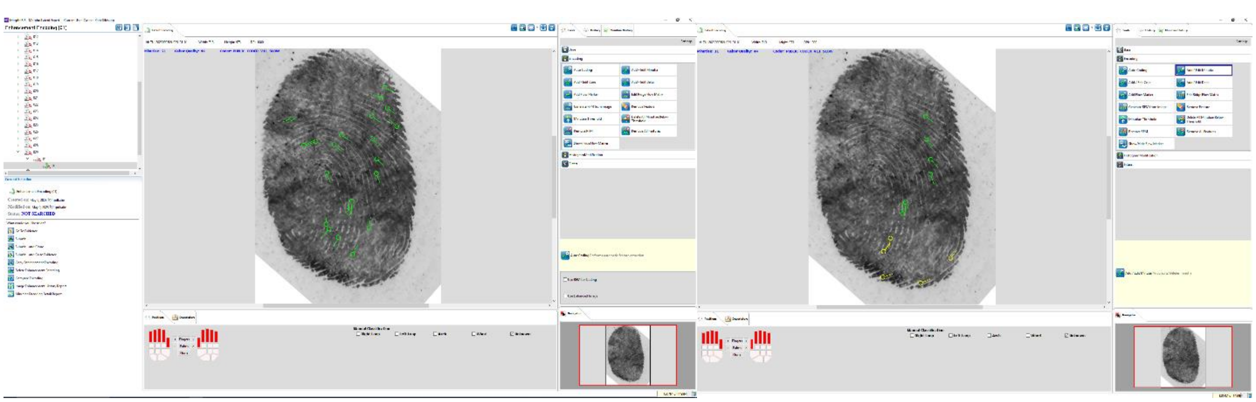

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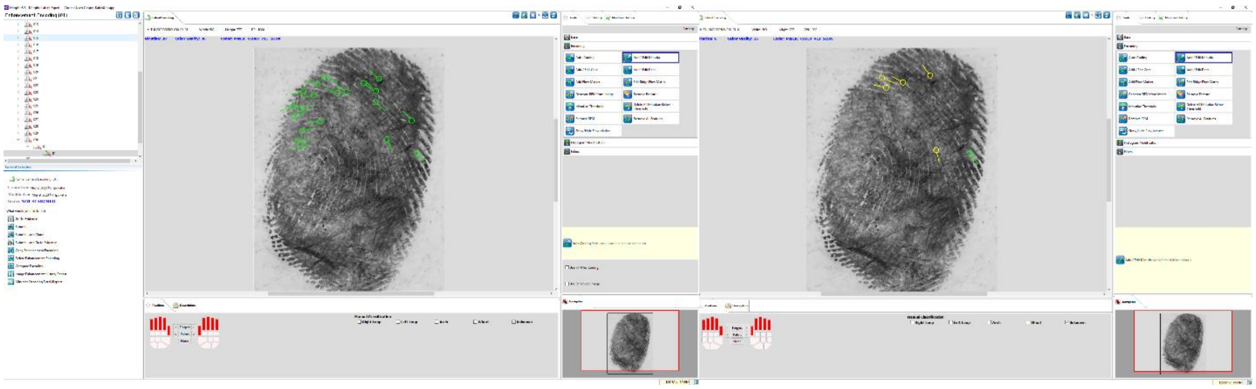

15C

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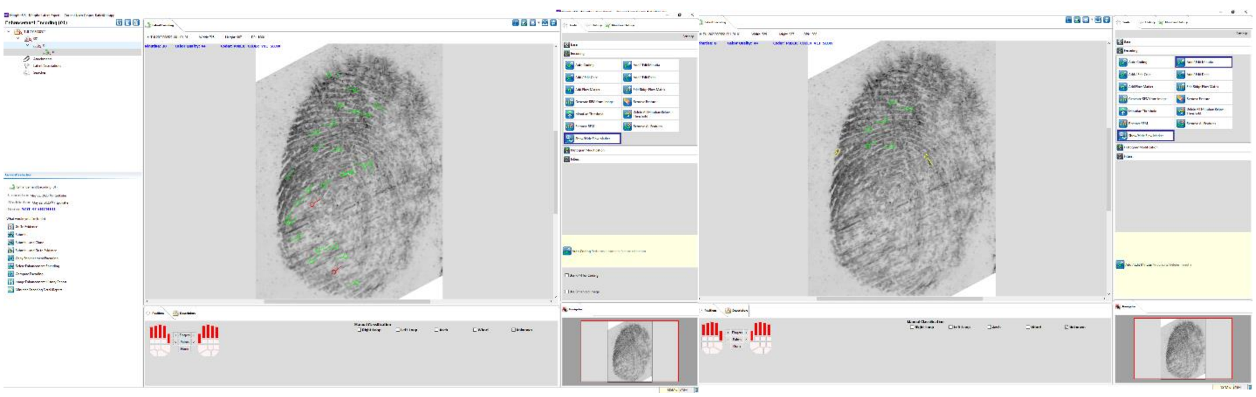
<u>*Before Clean-Up*</u> <u>*After Clean-Up*</u>



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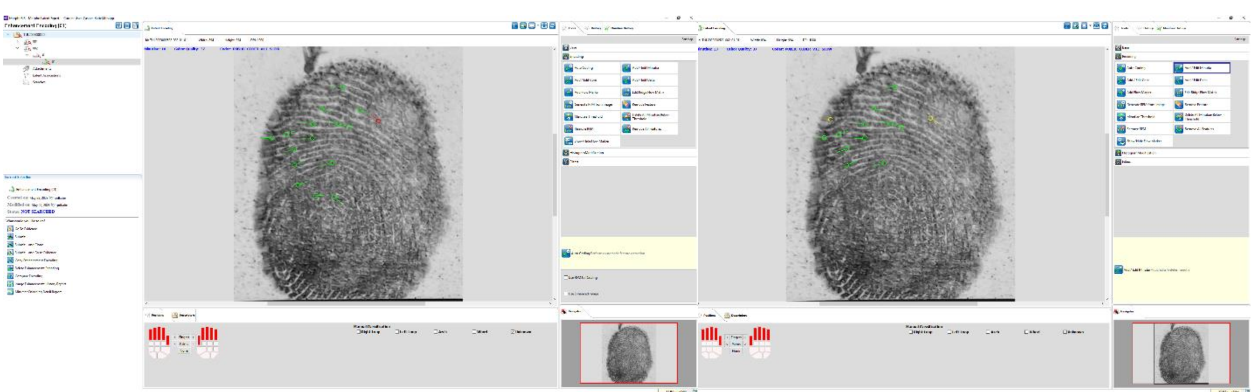

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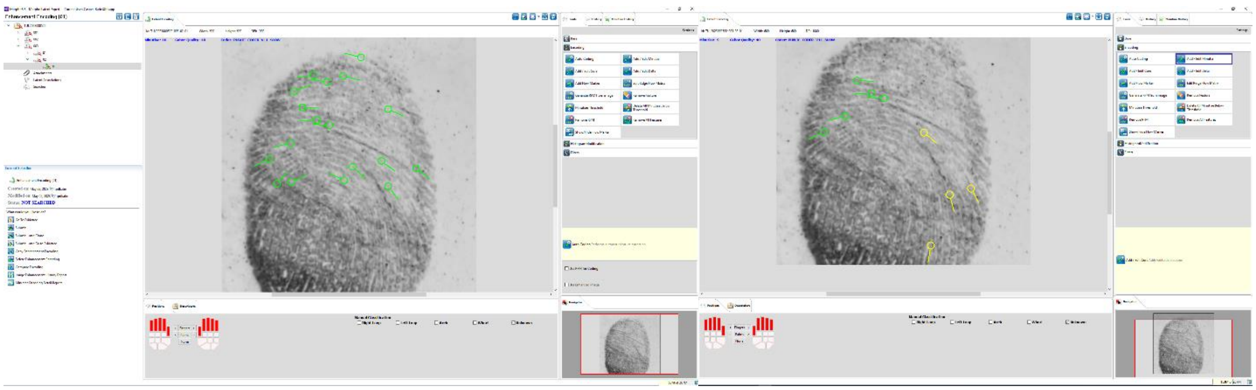

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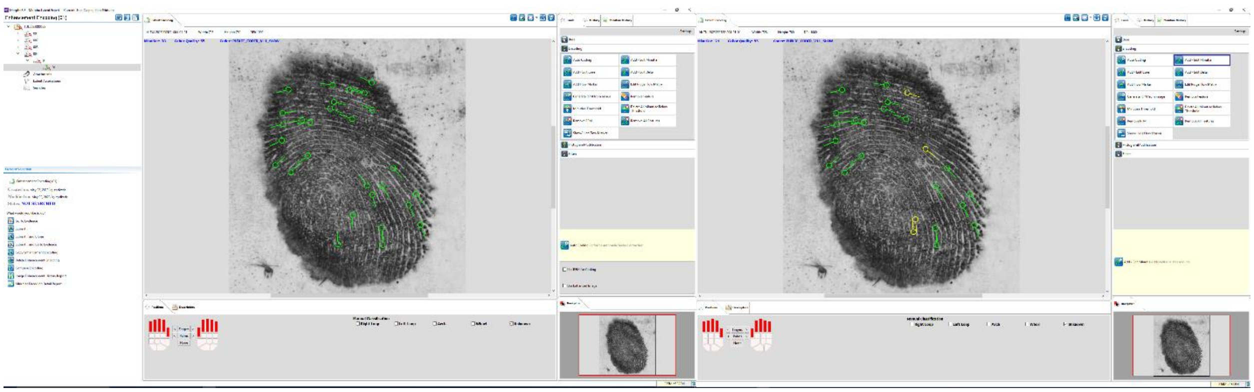

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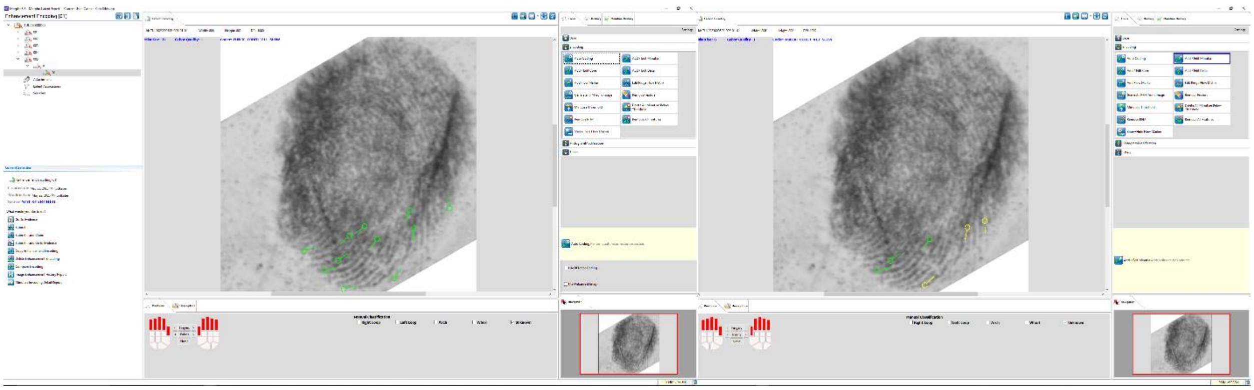

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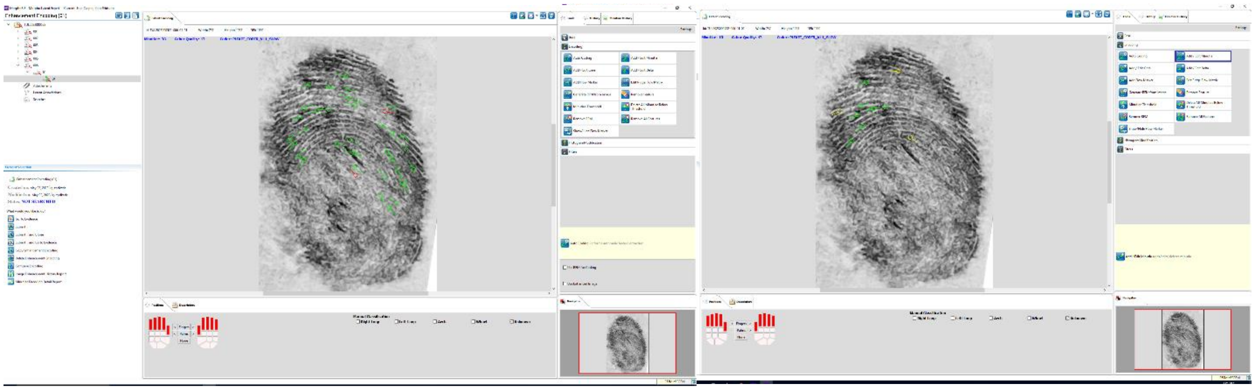

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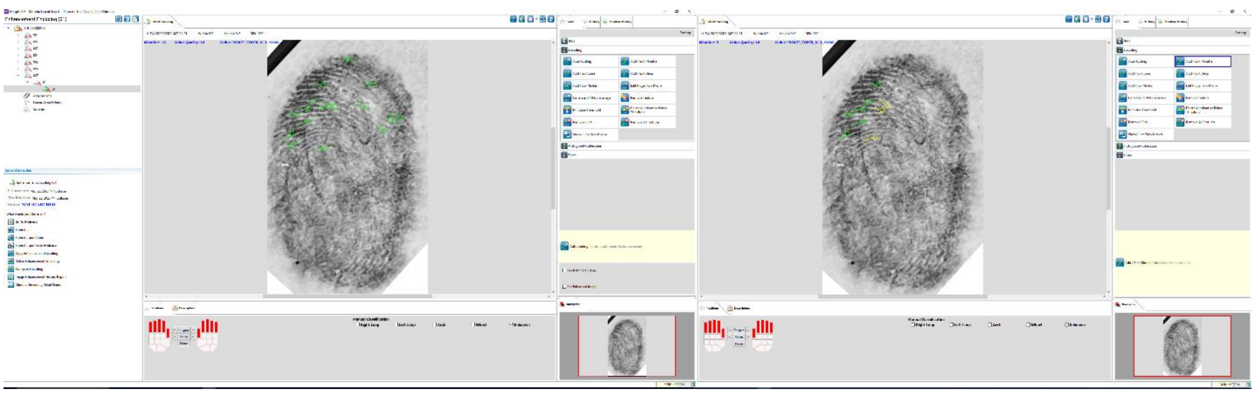

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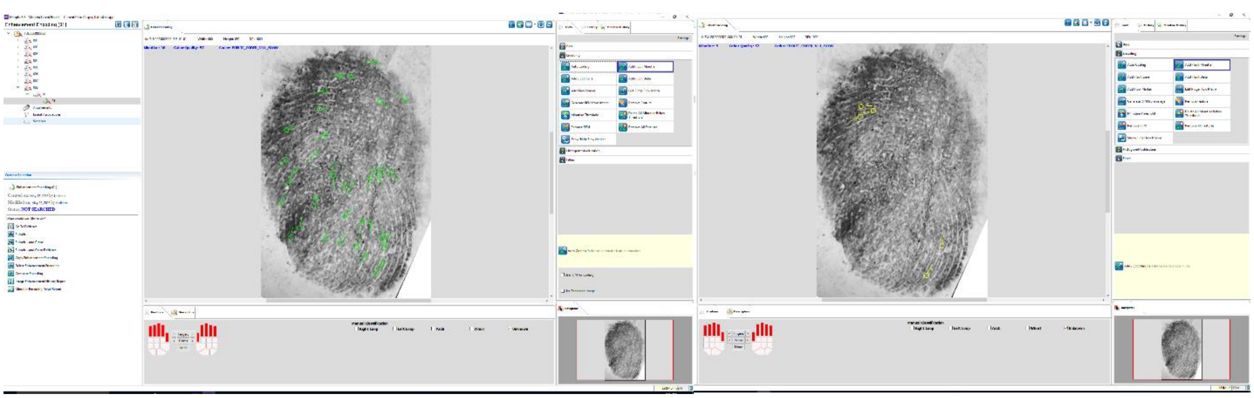

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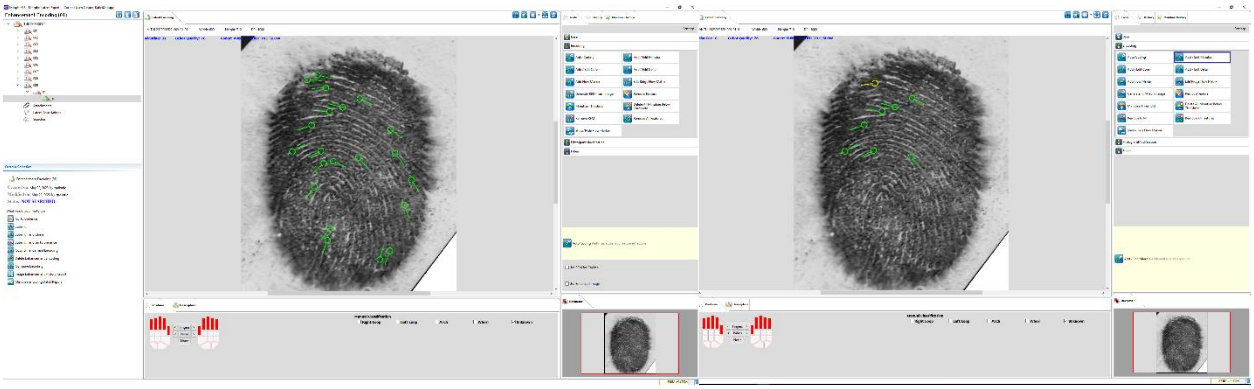

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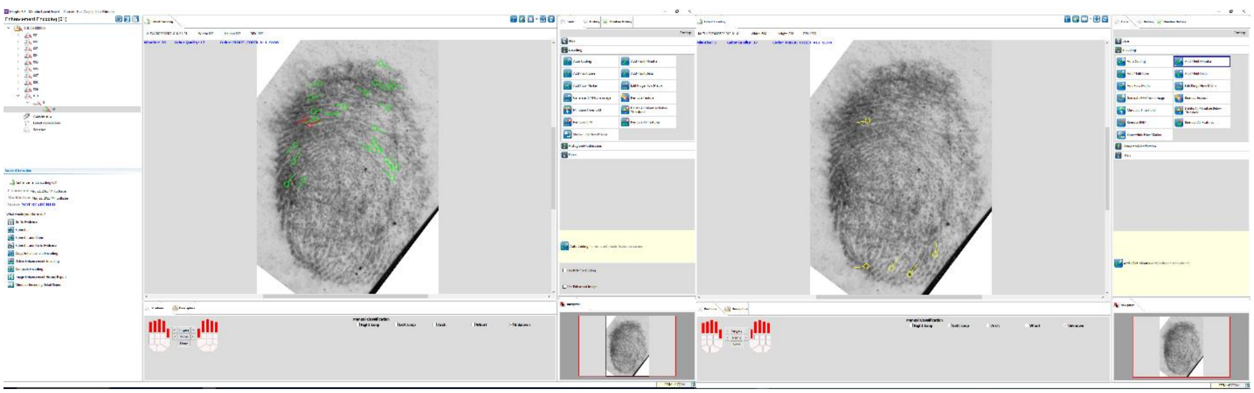

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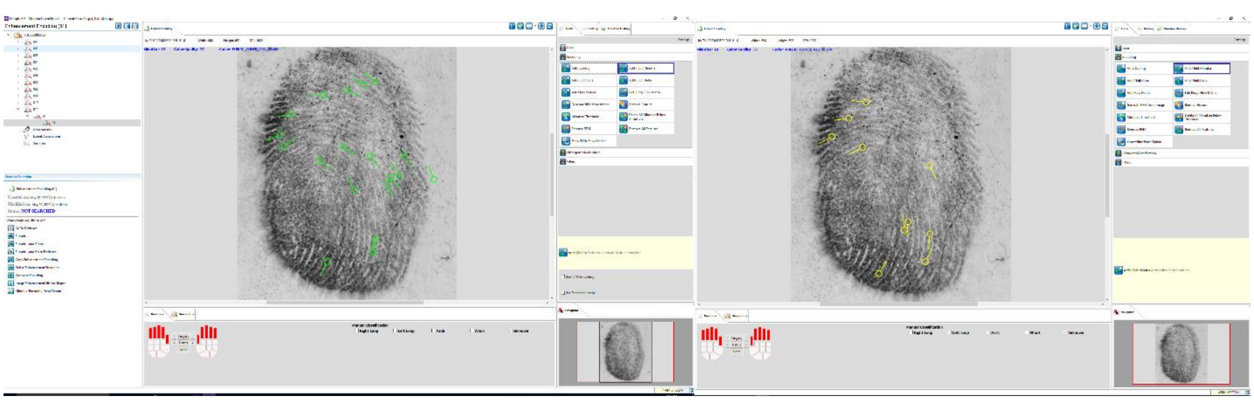

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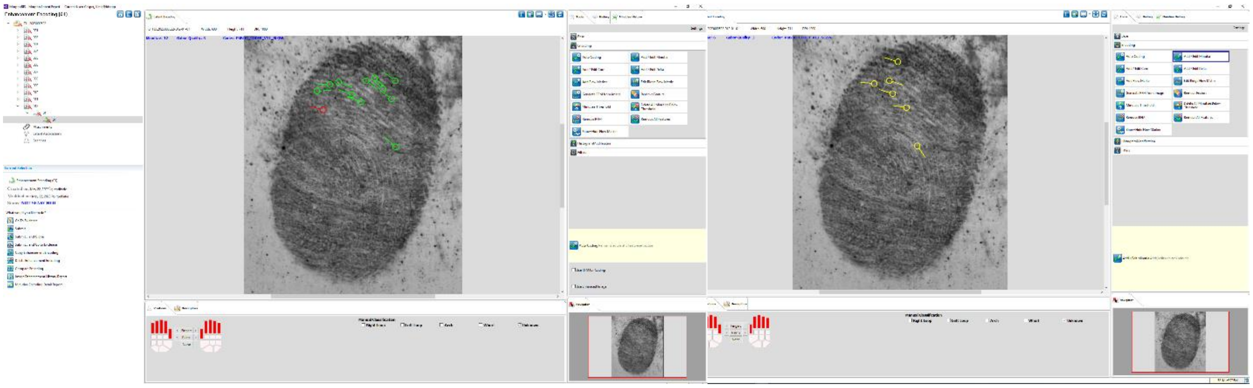

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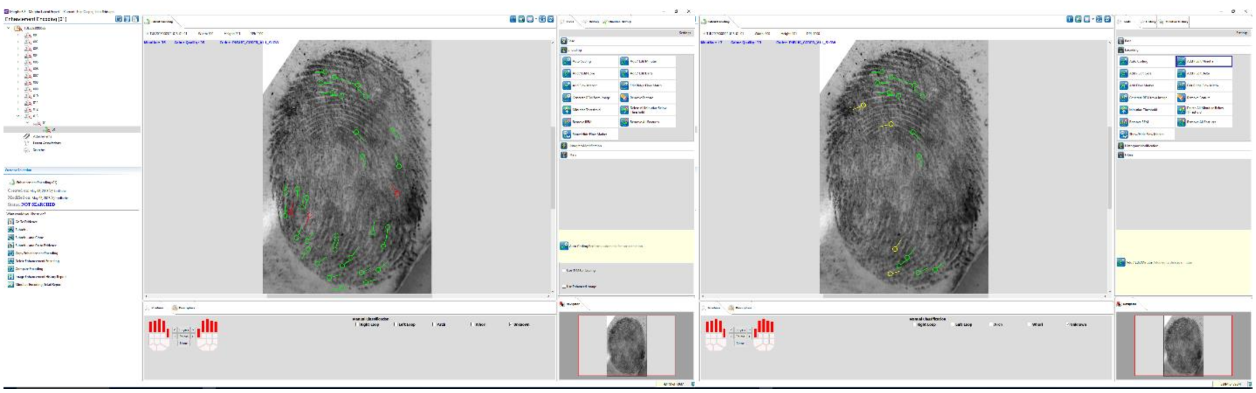

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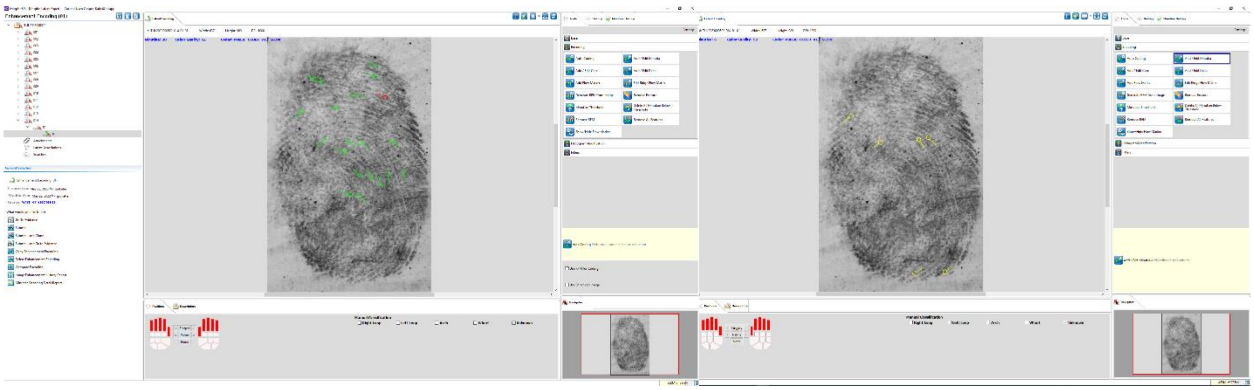

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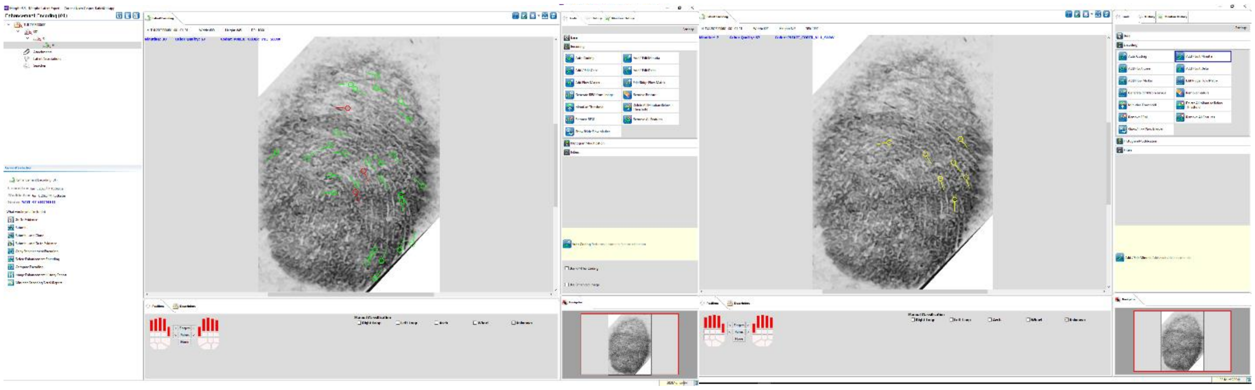

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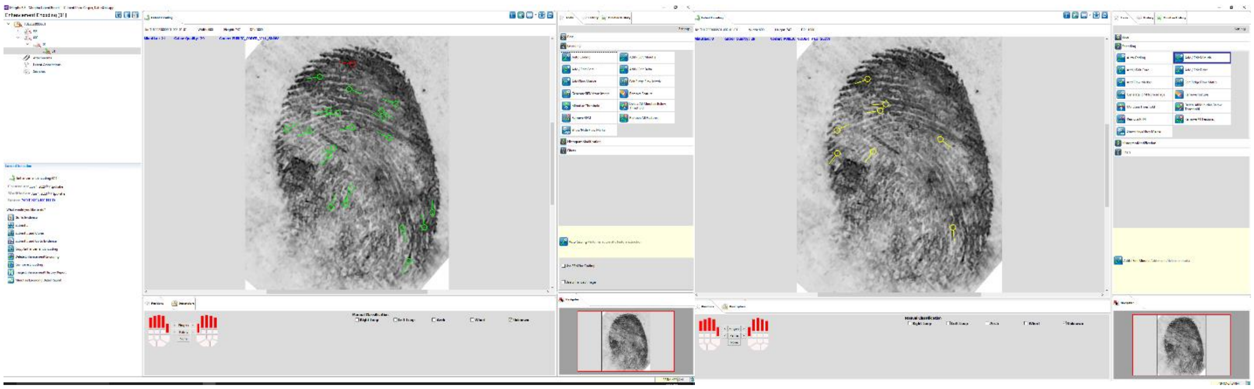

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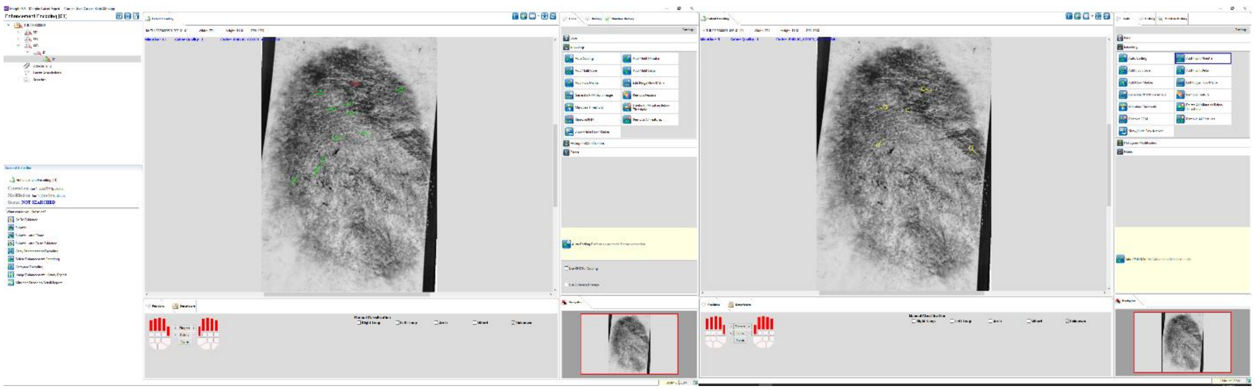

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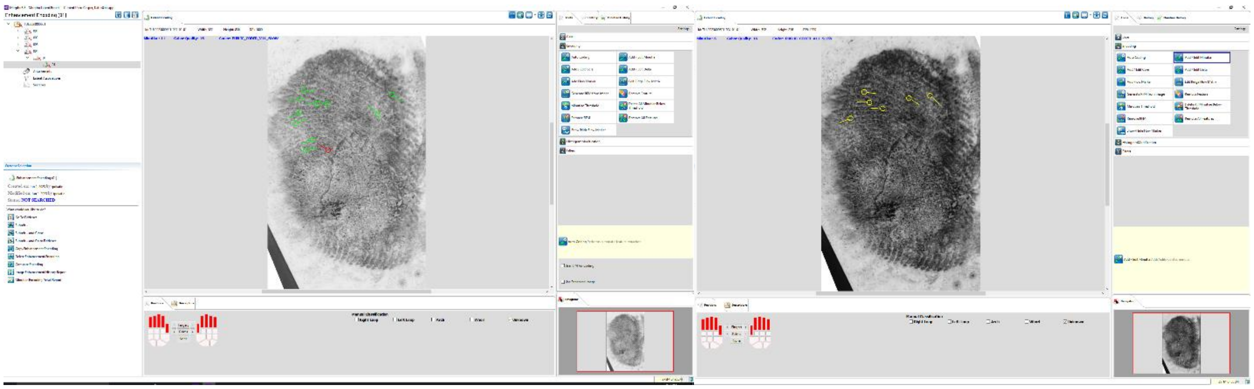

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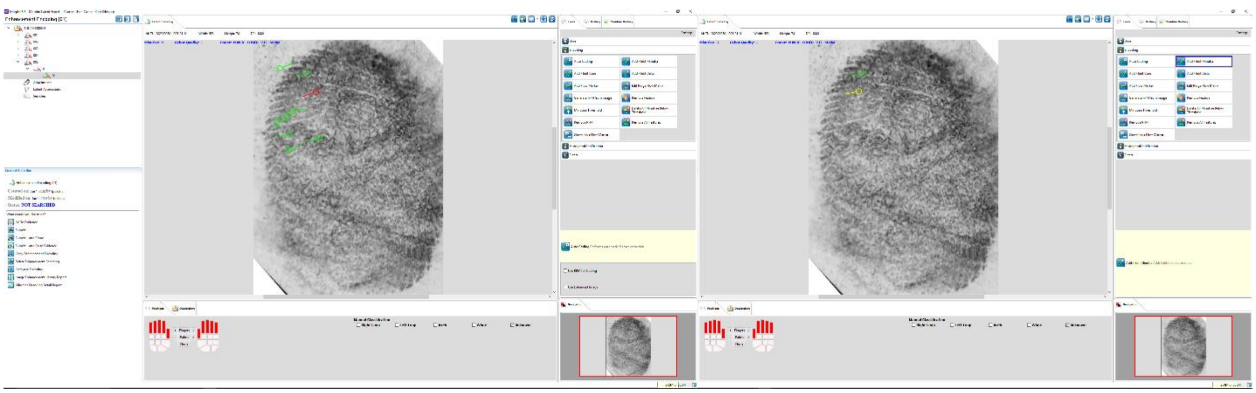

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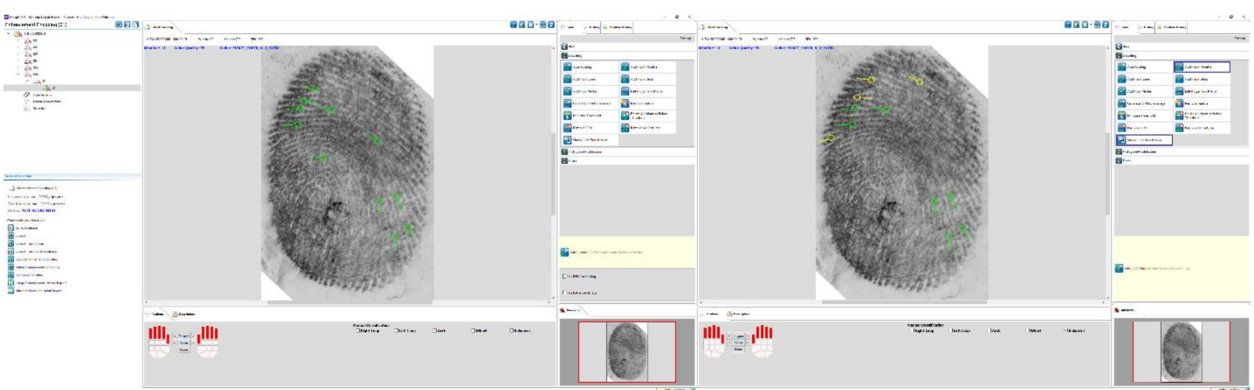

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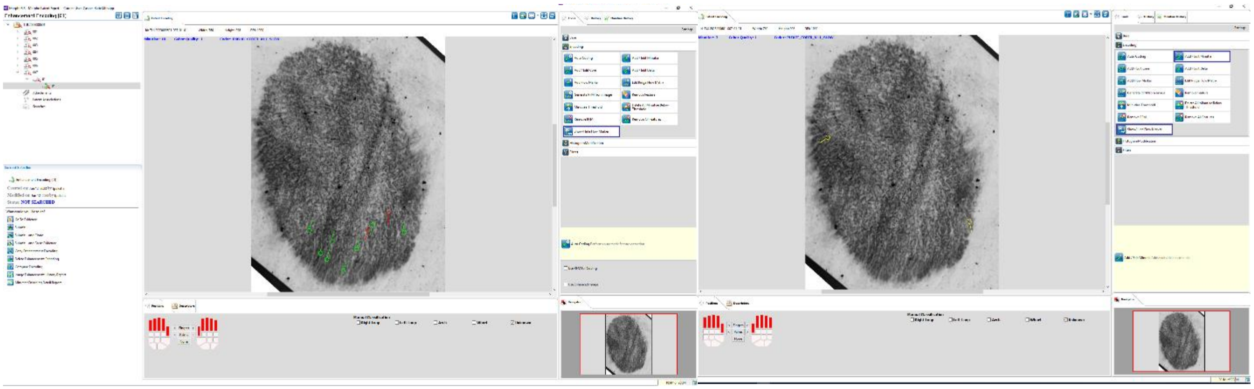

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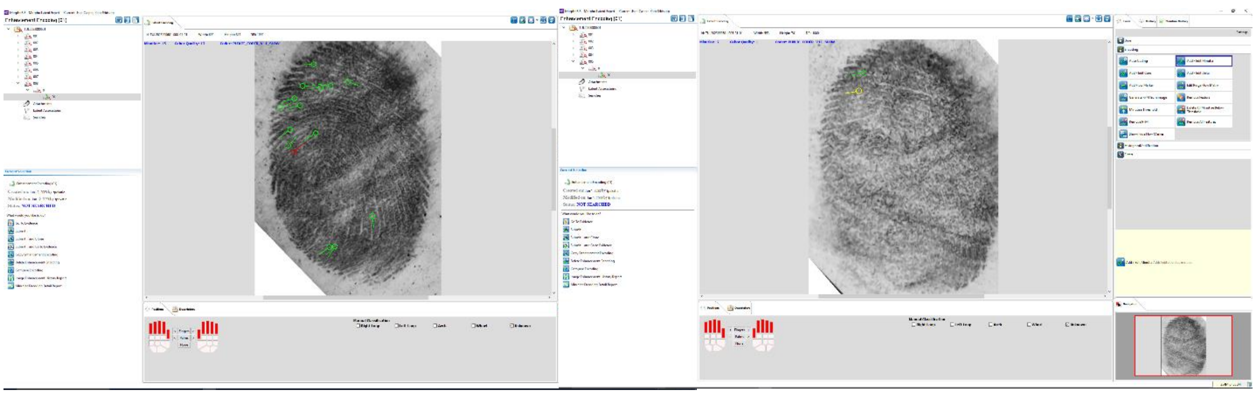

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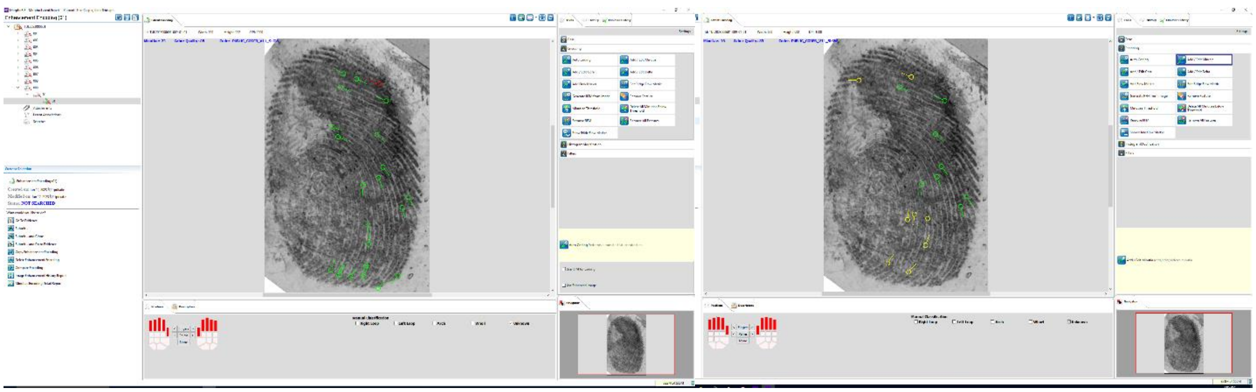

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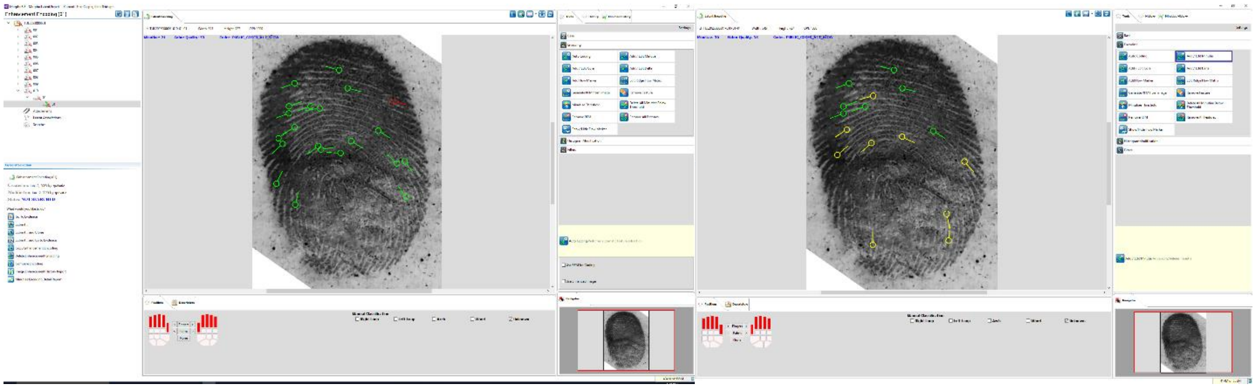

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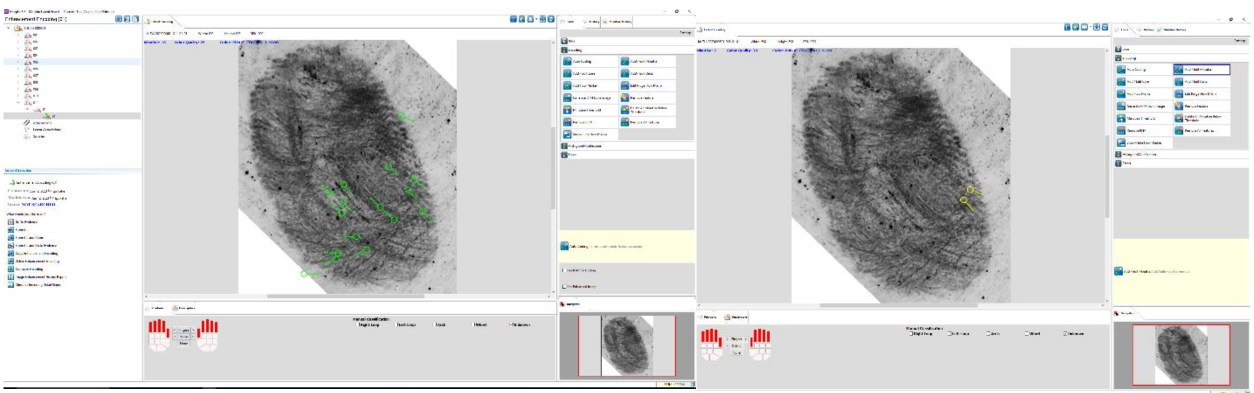

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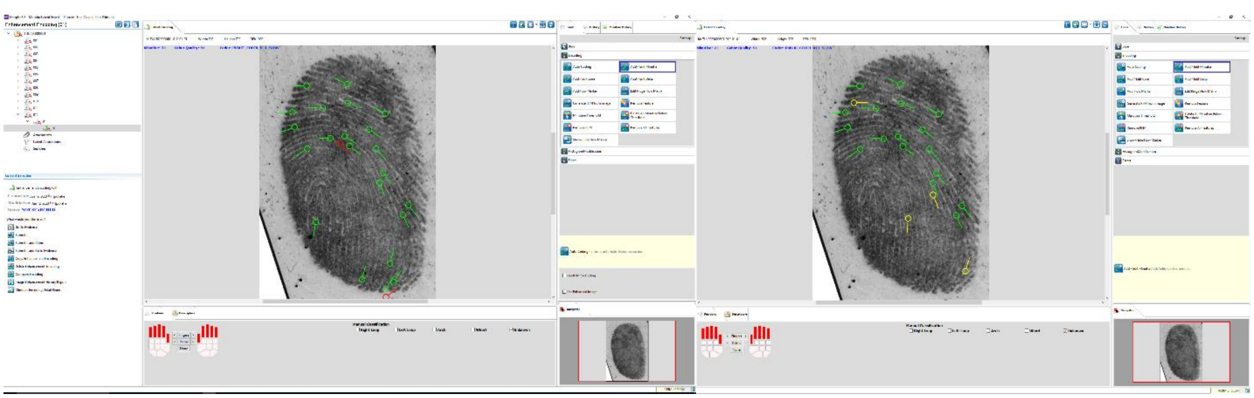

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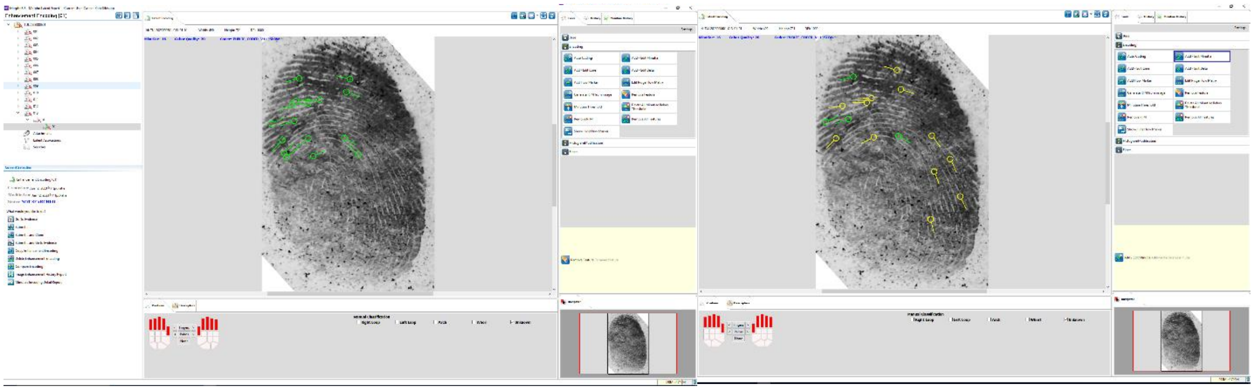

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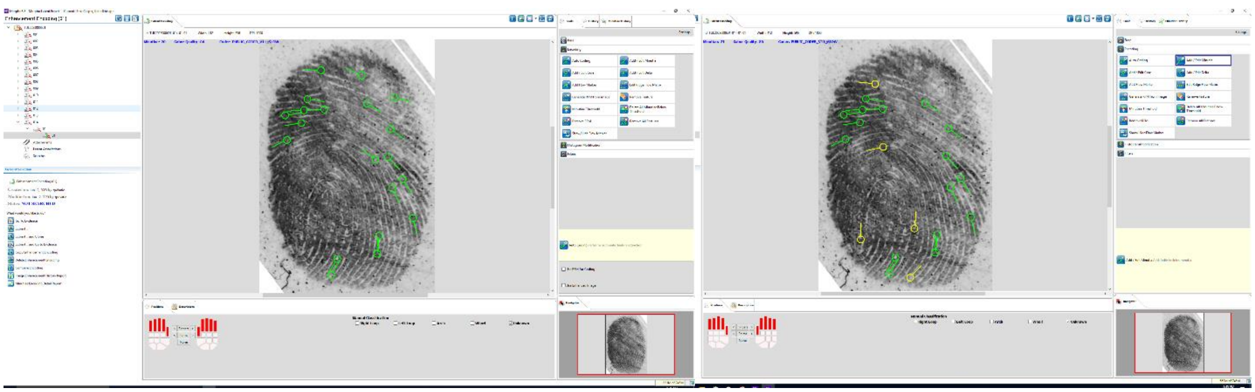

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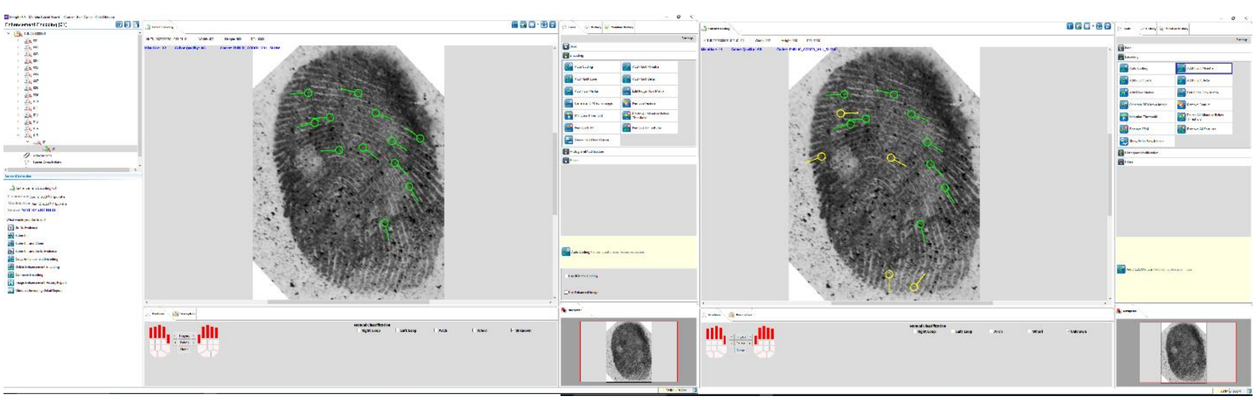

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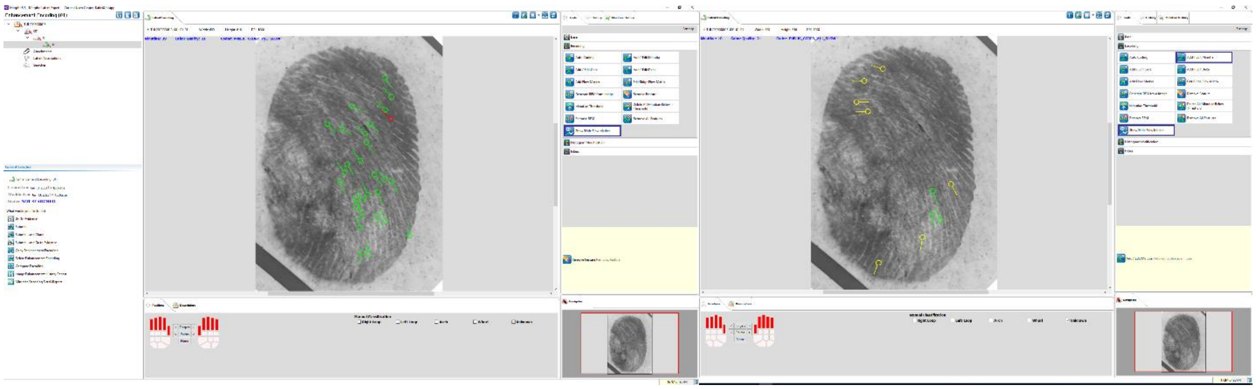

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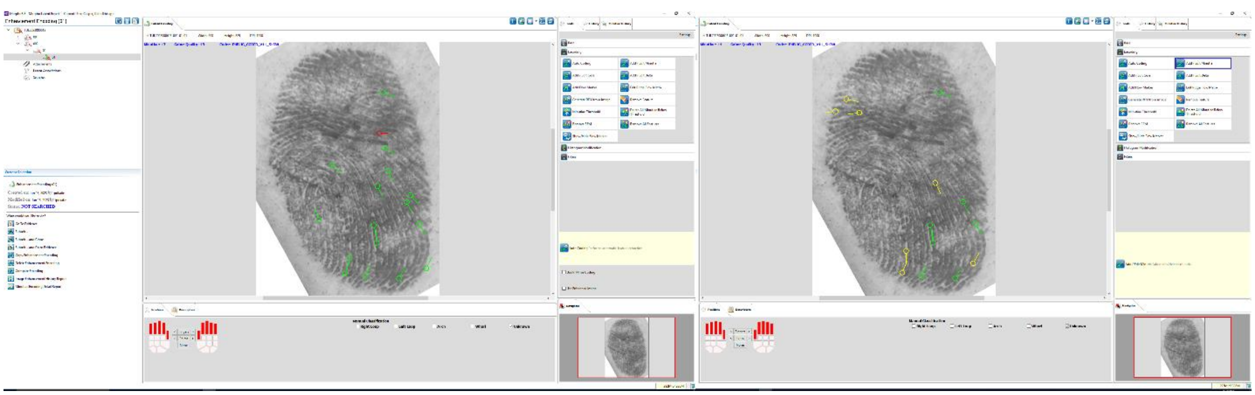

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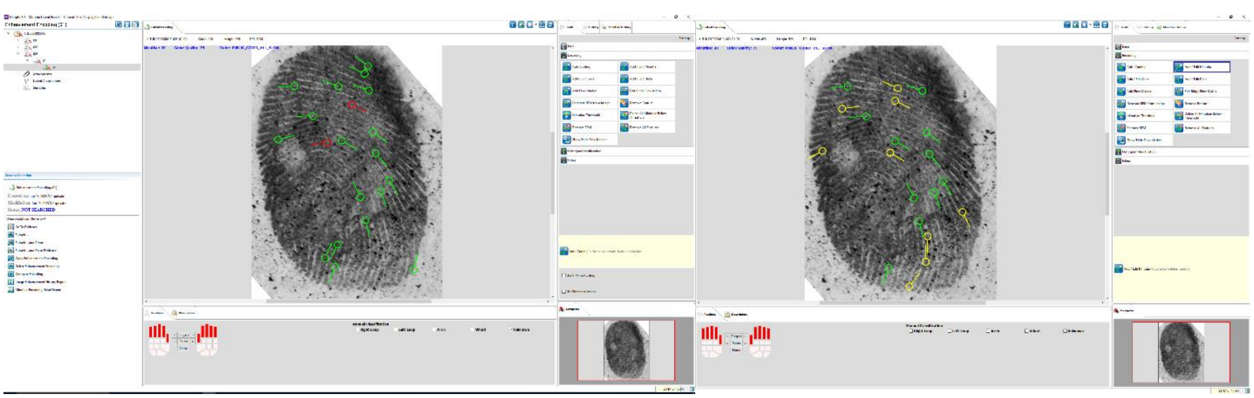

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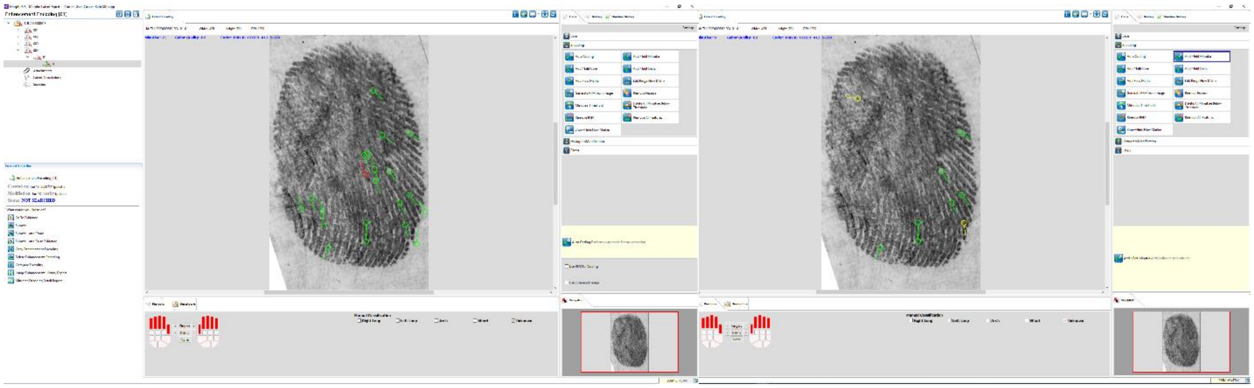

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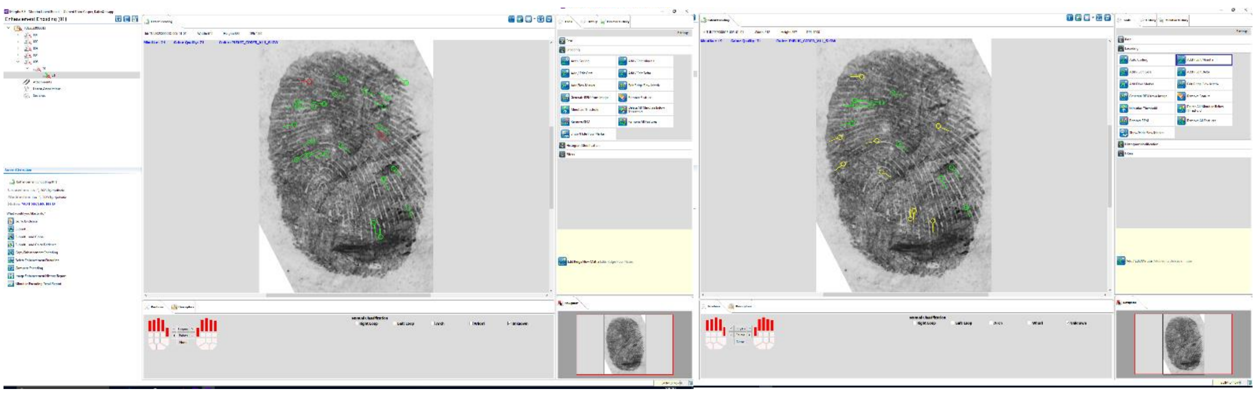

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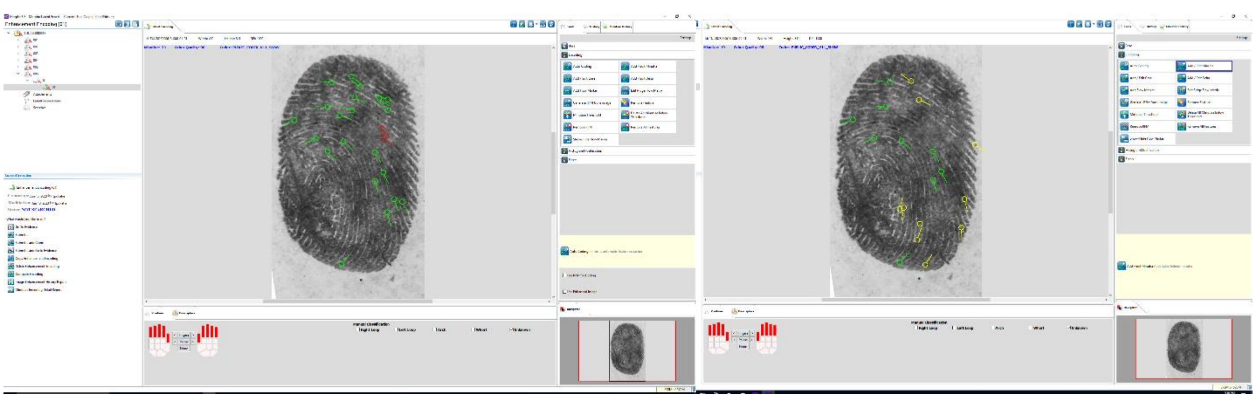

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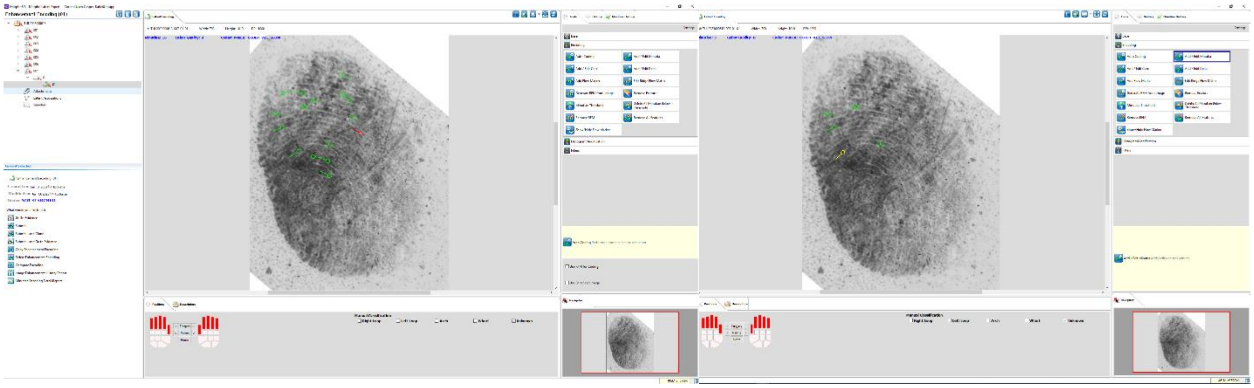

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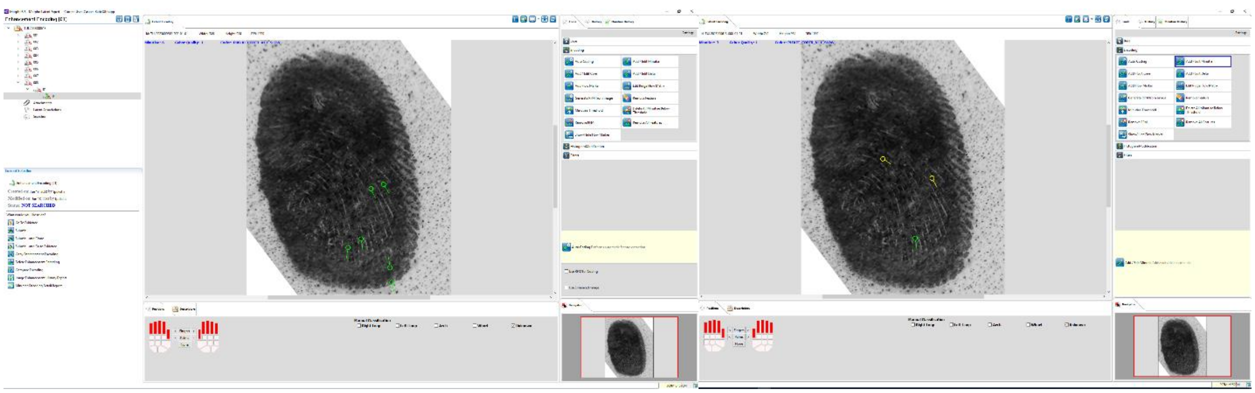

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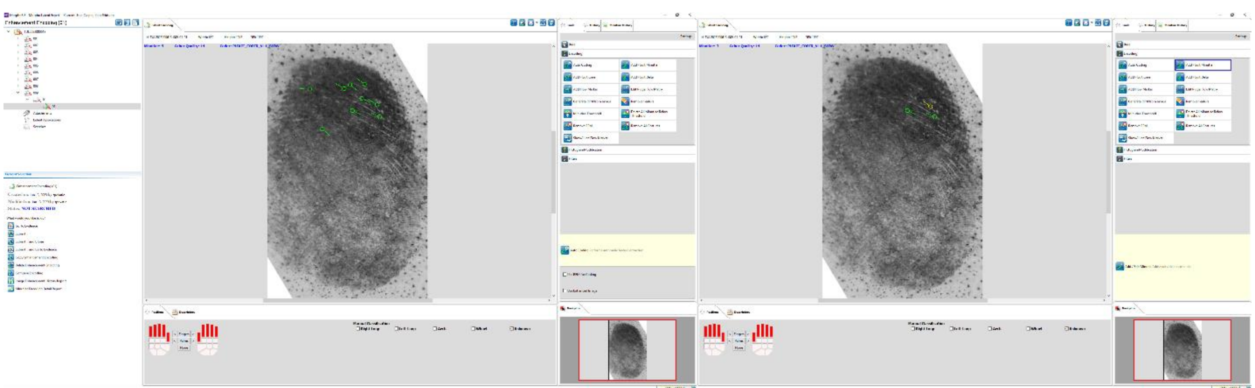

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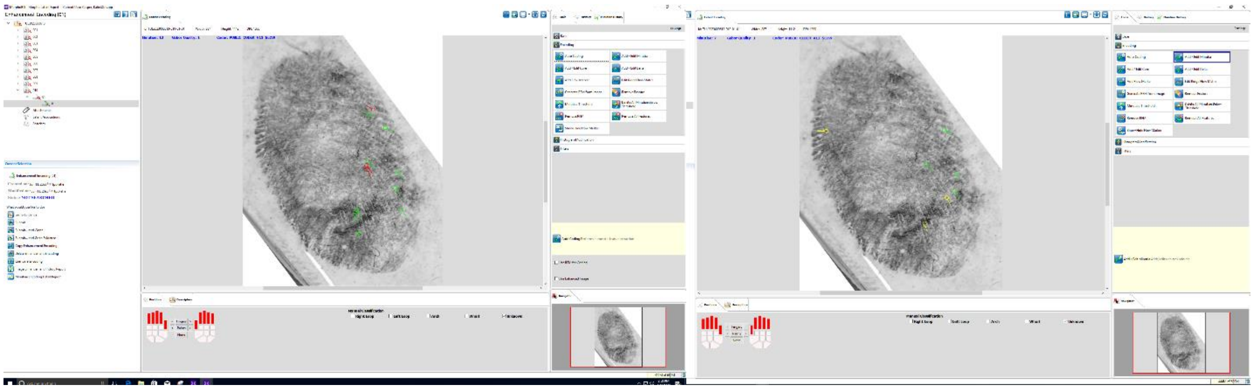

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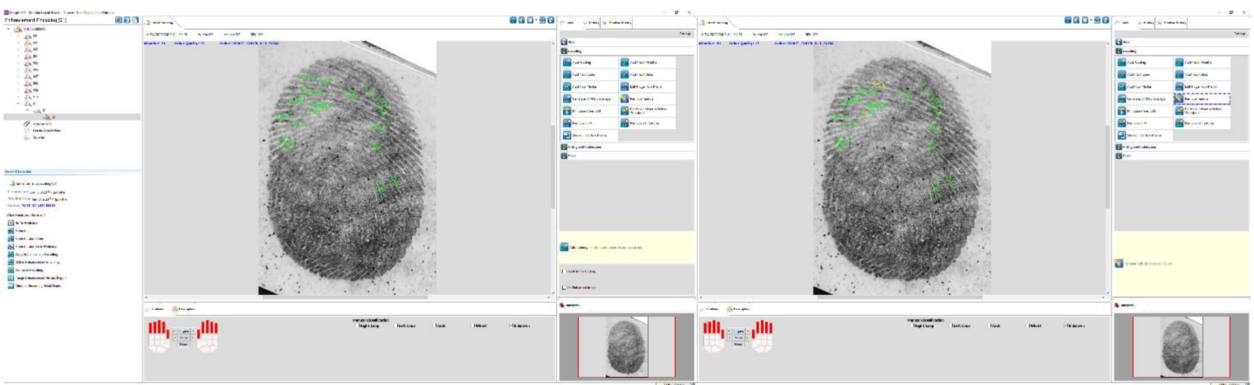

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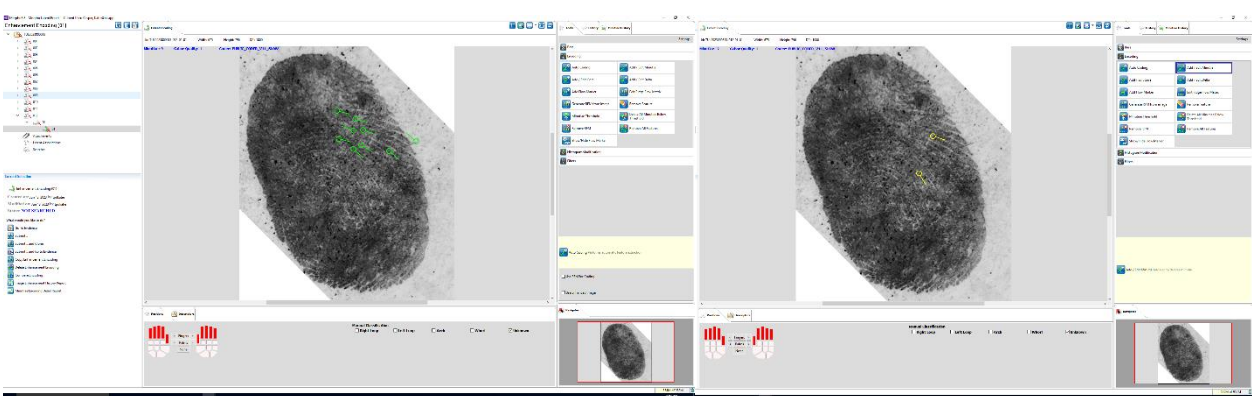

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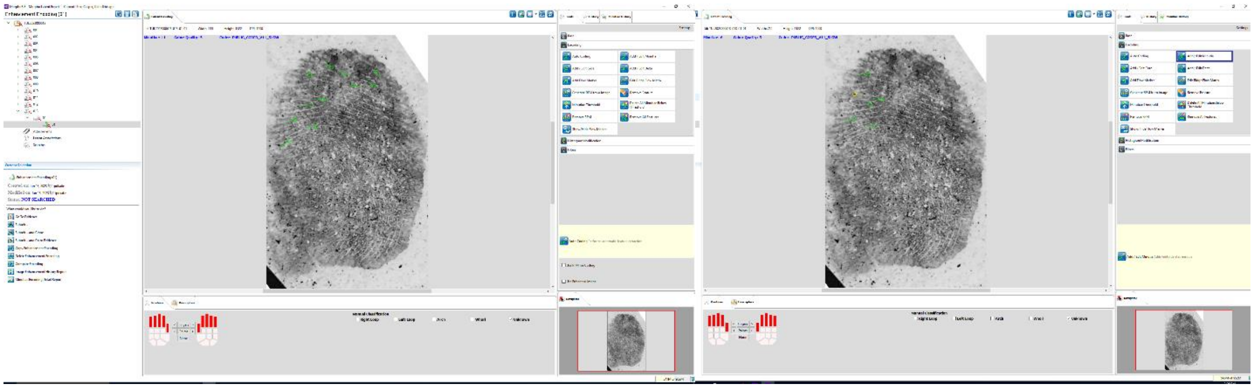

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