Laid Paper Mold-Mate Identification via Chain Line Pattern (CLiP) Matching of Beta-Radiographs of Rembrandt's Etchings

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Summary

This document describes a project – initiated late in 2012 – to use the chain line patterns apparent in beta-radiographs of the prints of Rembrandt to help identify mold-mates, i.e. papers made from the same mold, among those prints lacking watermarks.

Background

An ultimate objective of technical examination of laid papers is to help determine their date and location of manufacture. Prior to the mid-18th century laid papers were made by scooping paper pulp with a mold comprised of a screen within a rectangular wooden frame (Hunter, 1978) (Loeber, 1982). The screen allowed the water to drain from the pulp leaving a sheet of paper – sized by the borders of the frame – that would be removed to dry. The mold-based procedure for producing laid papers described in (Hunter, 1978) and (Loeber, 1982), leaves impressed features, including chain and laid lines and watermarks, detectable as thinner locations on a sheet of paper.

Transmitted light photographs and beta-radiographs are often proposed for revealing these impressions as the thinner portions of the paper impede the signal less and therefore stand out in the image produced. Transmitted light photographs have the disadvantage that the printed image also impedes the received signal thereby obscuring the chain line indentations. Beta-radiographs do not suffer from this problem, though beta-radiographs are more expensive to produce due to radiation licensing requirements and processing costs. For the watermark catalog of (Ash and Fletcher, 1998)

> "[b]eta radiography was chosen to record the watermarks ... because it is accurate, relatively simple to use, and produces sharp, clear images that are reproduced easily."

A beta-radiograph of “The Hog”, Bartsch number (B)157, first state (i), in Figure 1, clearly displays vertical chain lines separated by about 25 mm or 1 inch and the bottom portion of a watermark. The laid lines appear as closely spaced horiozontal lines. Laid lines are frequently quantified by density per cm or inch.

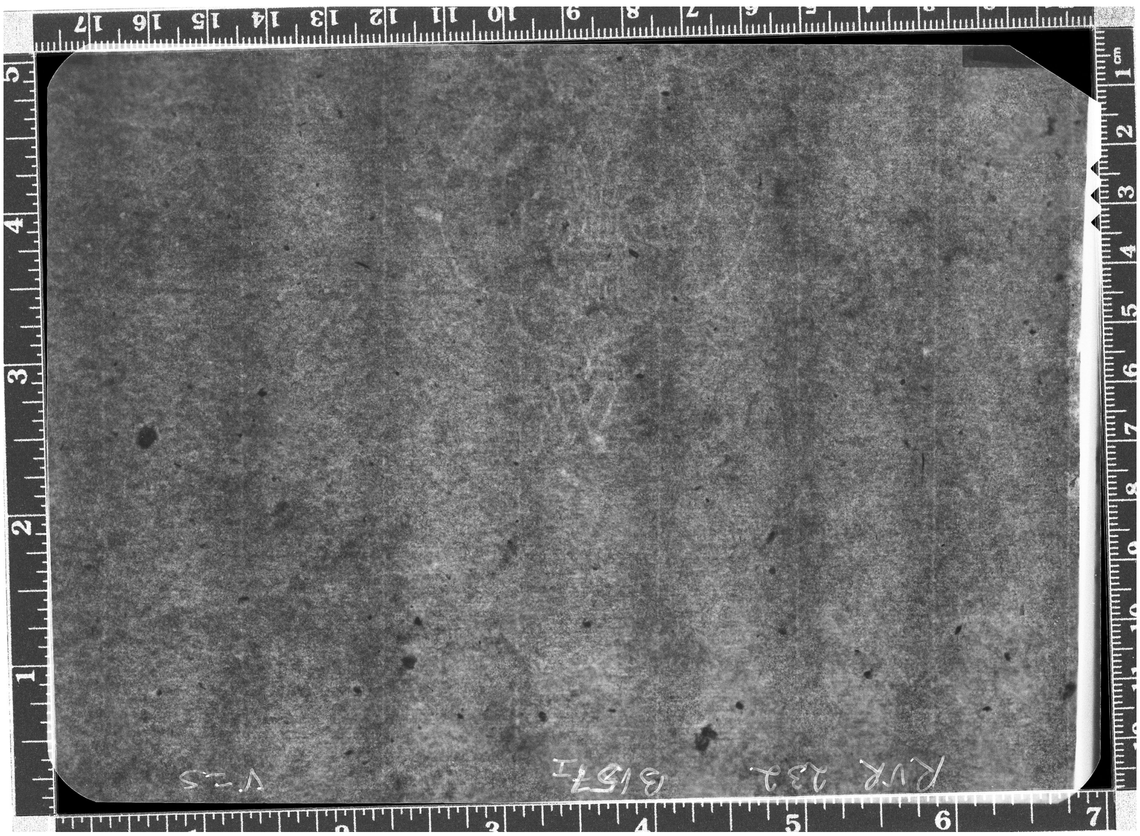

Figure 1: Beta-Radiograph of B157i from the collection of the Morgan Library & Museum

Currently, laid paper identification is based primarily on the exact matching of watermarks and the adjacent chain line patterns as promulgated by (Stevenson, 1954) and pursued in (Ash and Fletcher, 1998) and (Hinterding, 2006). Connecting a pair of sheets of paper via such a match can be used to support dates of manufacture of the two sheets of paper within a tight range.

> “Papers were regarded the same only if the watermarks were superimposable. This makes it probable that papers designated as the same ... actually were produced on the same or twin molds within a fairly short period of time” (Ash and Fletcher, 1998)

The desire to identify laid papers lacking watermarks is prompted by the realization that a large percentage of laid papers of interest do not include watermarks. Among Rembrandt’s prints approximately two thirds of them lack a watermark.

Chain lines, not just those in the vicinity of the watermark, have long been promoted as key identifying features for pre-1750 laid paper.

> “... chainlines can be seen in any margin, if the paper is ”laid”. Their regularity can be observed, their spaces measured, their sewing marks noted, their

> indentations studied for the information they may afford concerning the making of books. Though most characteristics of chains persist in machine-made laid, their evidential value is particularly clear in paper made at the vat." (Stevenson, 1954)

Indeed, the chain spacing sequence across a full sheet of paper has even been proposed as a unique identifier not requiring watermarks.

> "The measurement of the spaces between chain lines for an entire sheet of paper is probably the most fruitful extension of the earlier methods. Unlike watermarks, these lines are present in every leaf of paper manufactured before the introduction of wove paper in the later eighteenth century, and they can almost invariably be found in page margins, unobscured by type. Most important for identification, the spaces between the various chains in the paper I have examined are seldom the same. ... Equal chain spaces across a sheet are in fact rare enough to be a distinguishing quality of a variety of paper. In the paper of this period the openings usually vary by as much as 10% and sometimes even 20% within a given sheet, or by as much as 3 to 6 mm. Patterns become evident when the measurements are arranged in a series; these patterns serve to identify different paper moulds." (Vander Meulen, 1984)

Manual attempts have been made to collect sufficient chainspacing data across the full width of the paper for mold-mate identification.

> "In order to positively identify the products of specific mold pairs, I have developed a mug shot-and-fingerprint technique, which combines the mug shot, an image of the watermark (usually a careful freehand drawing) with the fingerprint, a chain-space model derived by measuring the width of each chain space to the nearest half-millimeter and then ordering the chain spaces so that they form a sequence representing the whole width of the sheet, minus trimming." (Hailey, 2007)

The amount of human time required to record the data necessary to accumulate a library of chainspacing sequences without great confidence that a half-millimeter accuracy in the data recorded would be sufficient to distinguish the papers of interest is an obvious impediment to the advance of this approach versus overlaying clear properly-sized watermark images to ascertain an identical match.

A desire to accumulate for a large library of distinct laid papers the features induced by the chain and laid lines that can be used for mold-mate identification demands an automated approach.

> "Especially the chain lines are important. All the sheets made in a particular sieve will have the same pattern of lines, and since the sieves were themselves all made by hand, no two are exactly the same. ... The chain and wire lines are in fact the 'fingerprint of the mould'. ... Since the ultimate aim is to construct a large database of all papers used in the Netherlands, automatic extraction of patterns of chain lines is important." (van der Lubbe, *et al.*, 2001)

The most recent in a sequence of 4 PhD theses on this matter at TU Delft studies the use of features, such as average laid line densities and chain line spacings, collected from overlapping patches across the entire surface of the sheet (Staalduinen, 2010). The accumulation of average densities of laid lines, which are assumed/observed to be quite regular in their spacing, for overlapping patches across the entire surface of the sheet of paper is similar to the problem of average thread density mapping for weave matching to identify canvas rollmate candidates among paintings from their x-radiographs (van Tilborgh *et al.*, 2012), (Leidtke *et al.*, 2012), (Johnson *et al.*, 2013). The chain line spacings are collected along a specific chain line segment in 2.2 cm chunks with 50% overlap. Experiments reported in (Staalduinen, 2010) indicate that

> "- Chain lines are more discriminative than laid lines.
>
> - Combining laid lines and chain lines is more discriminative than single feature representation."

A Visual Procedure

Consider the chain line pattern of (a portion of) a particular mold, as illustrated in Figure 2. Observe the similar, but unequal, spacings between nearly, but not exactly, parallel lines.

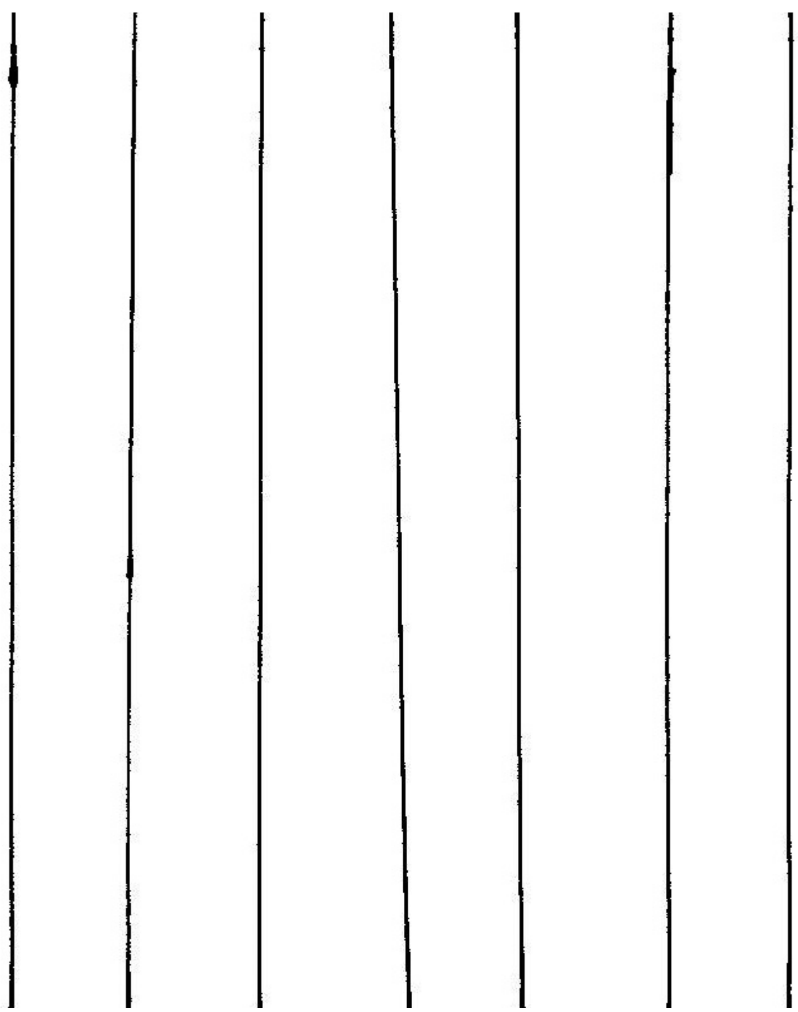

Figure 2: Mold Chain Line Pattern

The fourth line from the left (or right) in Figure 2 is the only line that is noticeably tilted.

Consider two pieces of paper made separately on this screen, the chain line patterns for which appear in Figures 3 and 4. The thicker spot near the top of the leftmost line in Figure 3 can be seen as the same artifact near the top of the leftmost line in Figure 2. A similar thick spot/artifact near the center of the second line from the left in Figure 2 can be related to this feature near the bottom of the second line from the left in Figure 3 and to the same feature in the upper half of the first line in Figure 4. This indicates that paper A is from the upper left portion of the mold and paper B is shifted to the right one line and down relative to paper A. This observation is unknown to the procedure.

One approach to check mold-mate status for these two papers (while unaware that they are mold-mates) lines up the leftmost line in each image and then considers the similarity of the chainspace sequence of the two images. Full assessment of a pattern match will require match examination for vertical and horizontal shifts. To avoid having to compare and horizontally shift, we instead extract all possible patterns of 4 adjacent lines form the original images, which yields four chain line patterns in Figure 5. Overlaying the chain line patterns of the four possible configurations between the two sets of spacing triples is illustrated in Figure 6.

If A1 matches B1, then we know they share the left most line in the chain line pattern of Figure 2 and the subsequent 4 chain lines to the right. If A1 matches B2, then the leftmost line in paper A in Figure 3 matches the line to the right of the leftmost in paper B in Figure 4. Similalry, A2 matching B1 indicates that the leftmost line in paper B is the same chain line as the line to the right of the leftmost in paper A. Finally, A2 matching B2 indicates the same relative configuration as a match between A1 and A2.

Of the four images in Figure 6 only the match between the second spacing triple in paper A, i.e. A2, and the first spacing triple in paper B, i.e. B1, in the bottom left of Figure 6 appears close. The three essentially vertical lines are matched precisely. The single pair of noticeably tilted lines are separate, but parallel and close. Such a pair of parallel tilted lines suggests a vertical shift will achieve a complete match, as shown in Figure 7, which realizes their original configuration in Figure 2.

An Experiment with Available Data

To test the potential utility of relying on matching chain spacing sequences alone to produce mold-mate candidates on available images of (partial) watermarks including at least 4 chain lines from suitable images of Rembrandt prints, we developed Mathematica code that allows us to mark the chain line intersections with the edges of the image of the paper. Further software extracts the sub-images of adjacent space-triples. A distance measure is then used to rank the closeness of the patterns of all pairs of chainspace triples.

We have 92 scanned (at 150 dpi) beta-radiographs each with 4 to 10 chain lines from the collection of the Morgan Library & Museum. (See appendix to this document for a list noting Bartsch numbers.) There are 31 with only 4 chain lines, 37 with 5, 15 with 6, 7 with 7, none with 8, and one each with 9 and 10. These images produced 375 triples. A computed top-10 match among these triples is of B96 and B157i (Schwartz, 1977):

B96 / “St. Peter in pentitence”, VxH: approximately 5 1/4” x 4 3/4”

B157i / “The hog” (first state), VxH: approximately 5 3/4” x 7 1/8”

The “Bartsch Concordance” appendix of (Ash and Fletcher, 1998) notes that the Morgan Library has (a) B96 with a fragment of a watermark called Strasbourg Lily and (b) B157i

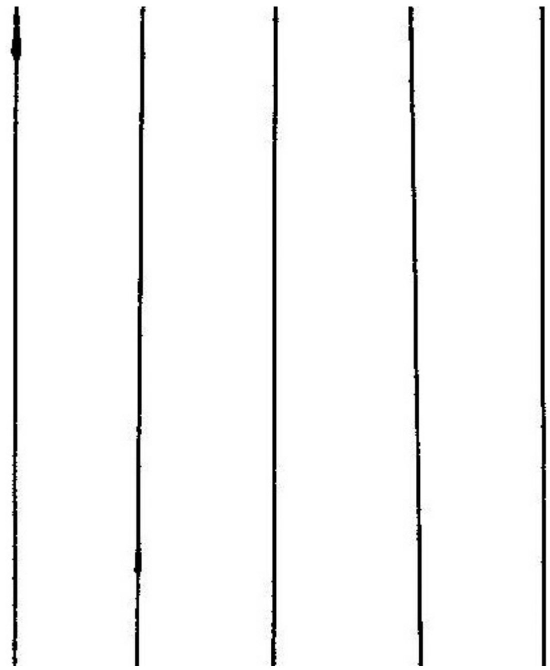

Figure 3: Paper Chain Line Pattern A

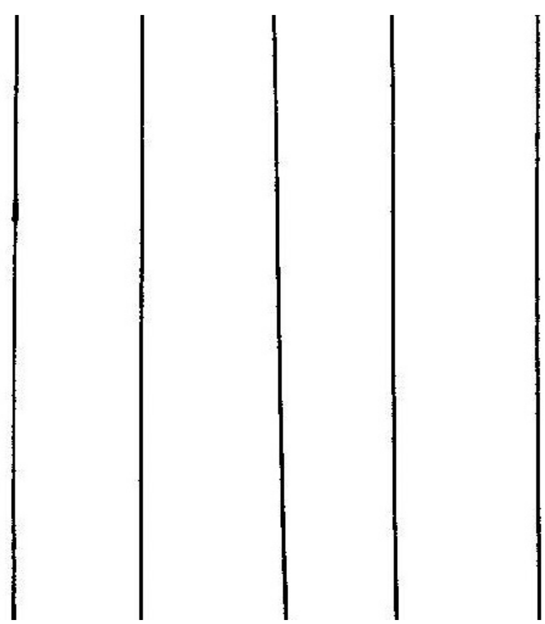

Figure 4: Paper Chain Line Pattern B

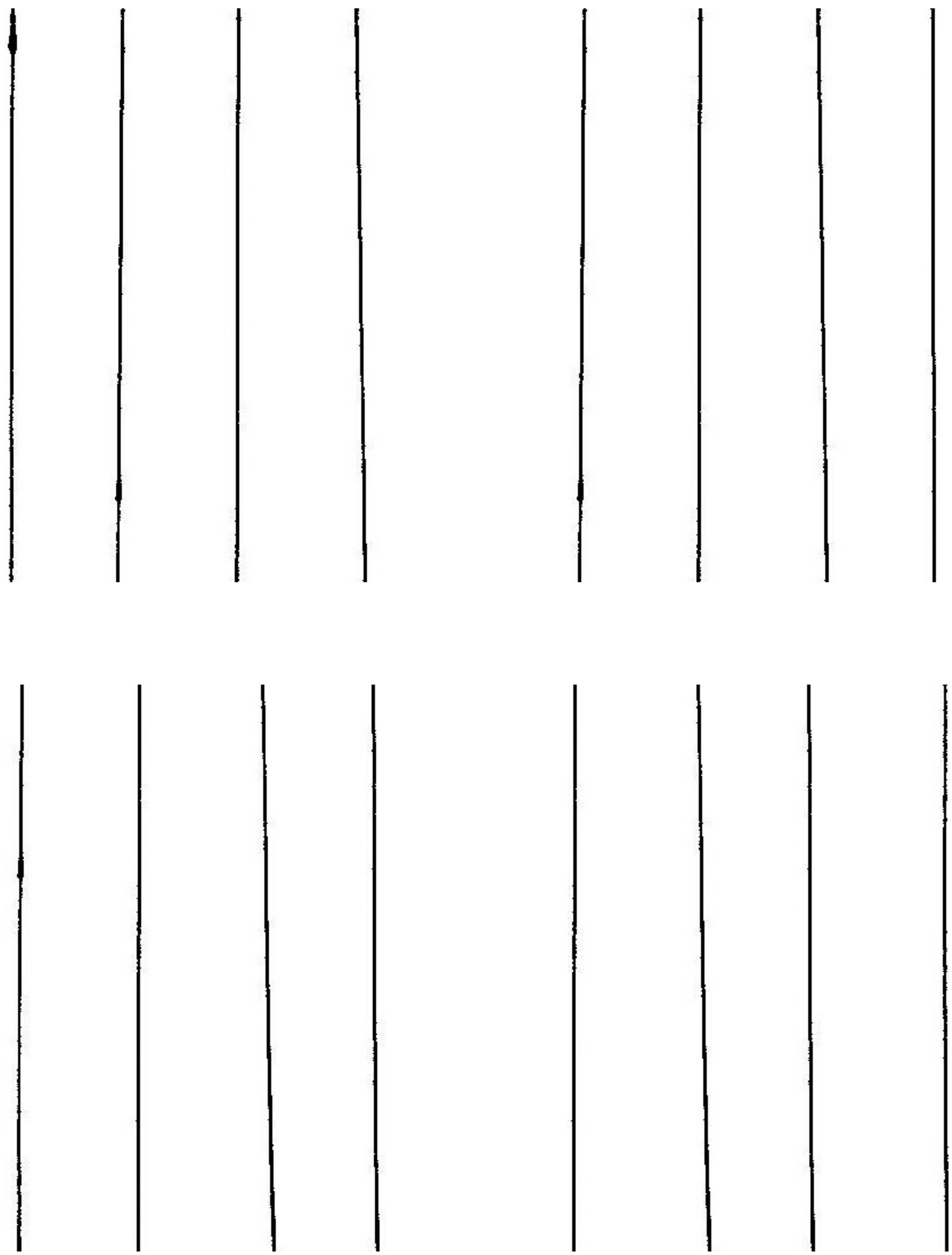

Figure 5: Paper Chain Line Pattern Triples (upper left: A1, upper right: A2, lower left: B1, lower right: B2)

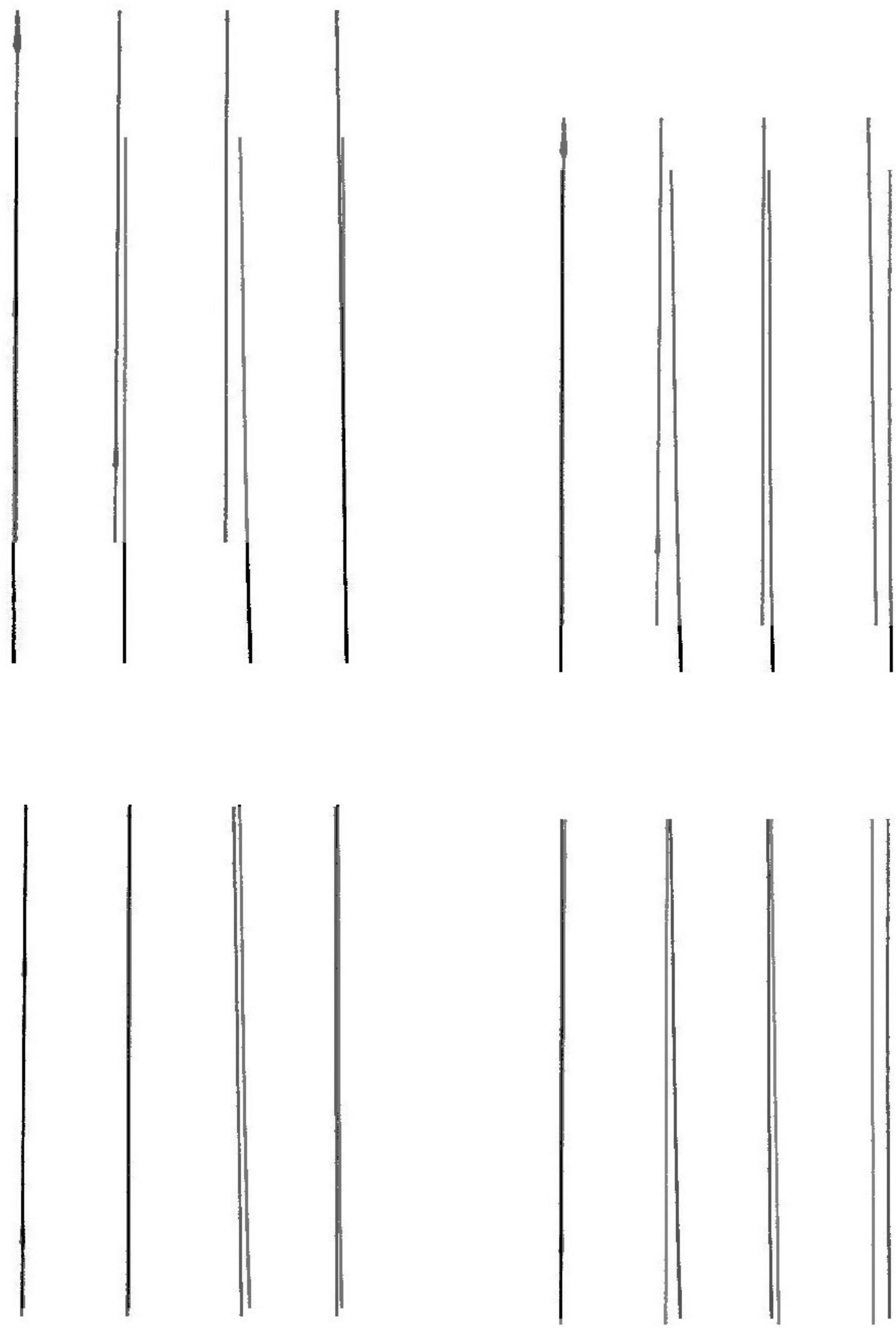

Figure 6: Overlays of Pairs of Triples (upper left: A1 and B1, upper right: A1 and B2, lower left: A2 and B1, lower right: A2 and B2)

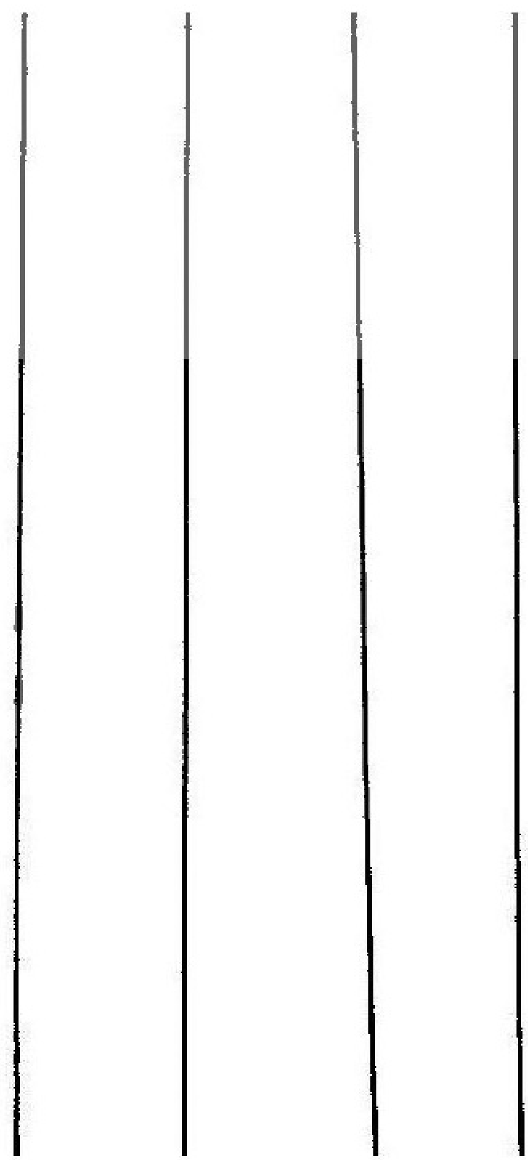

Figure 7: Chain Line Matching Mold Mates: A2 and B1

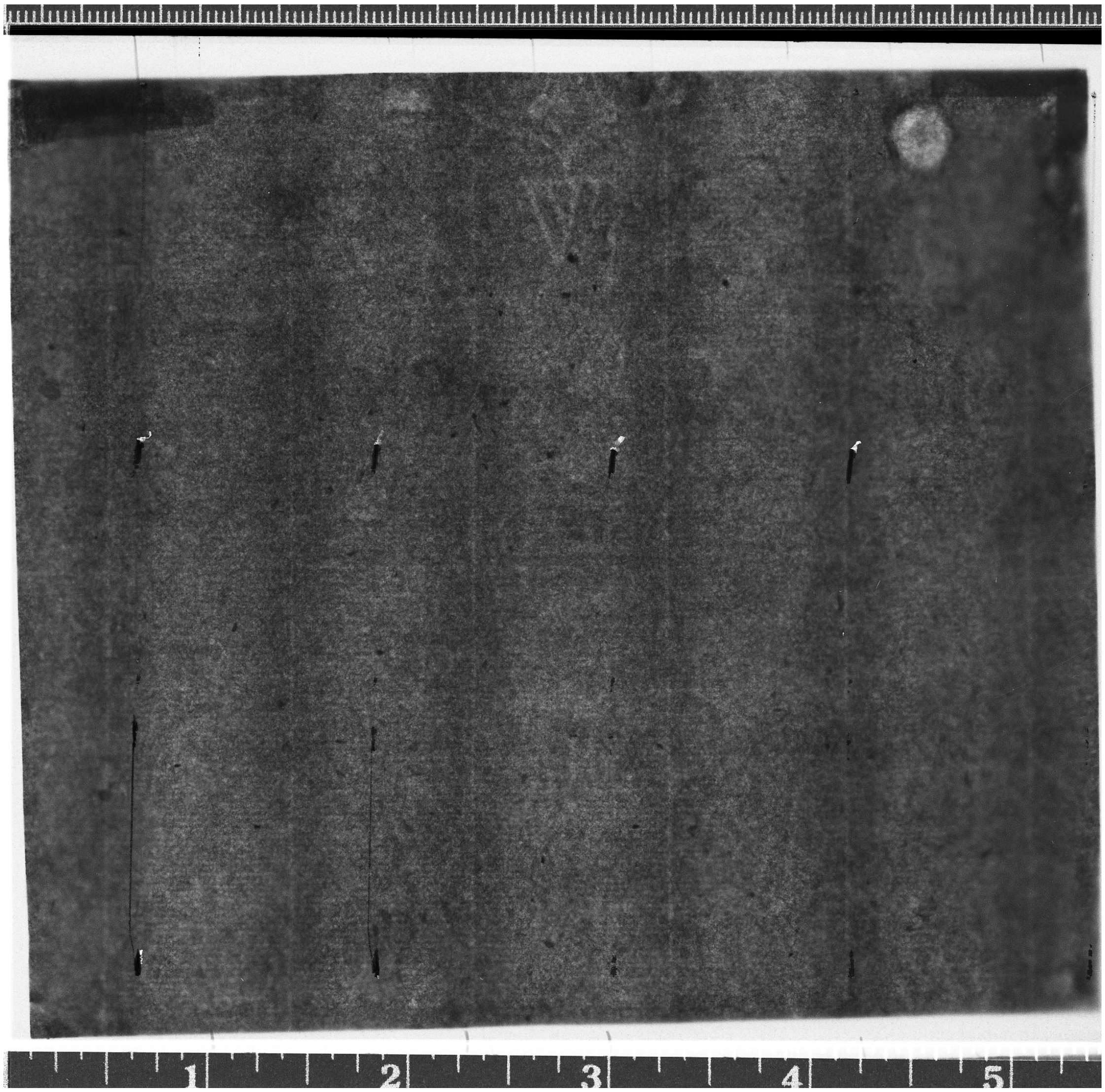

Figure 8: Beta-Radiograph of B96 from collection of the Morgan Library & Museum

with a Strasbourg Lily watermark. Actually, the watermark image in RvR 232 B157i is also incomplete. Not just the top tip of the fleur-de-lis and the top of the shield within which the fleur-de-lis is placed are missing, but also a crown above the shield that's half the height of the shield. The beta-radiograph of B157i is in Figure 1. The beta-radiograph of B96 is shown in Figure 8.

Unfortunately, the matching of chainspace triples also has the propensity for false matches. A pair of triples, also in the Top 10 matches among the 375 triples, link B188iv and B195ii, which actually have fragments of different watermarks, as can be seen in Figures 9 and 10 and is cataloged in (Ash and Fletcher, 1998).

Research Goal

The target of this effort is the collection of papers used by Rembrandt for his etchings. The strategy is to use automated chain line pattern matching to deliver a handful of top choices among this collection for a specific sheet of interest. Human experts will be provided access

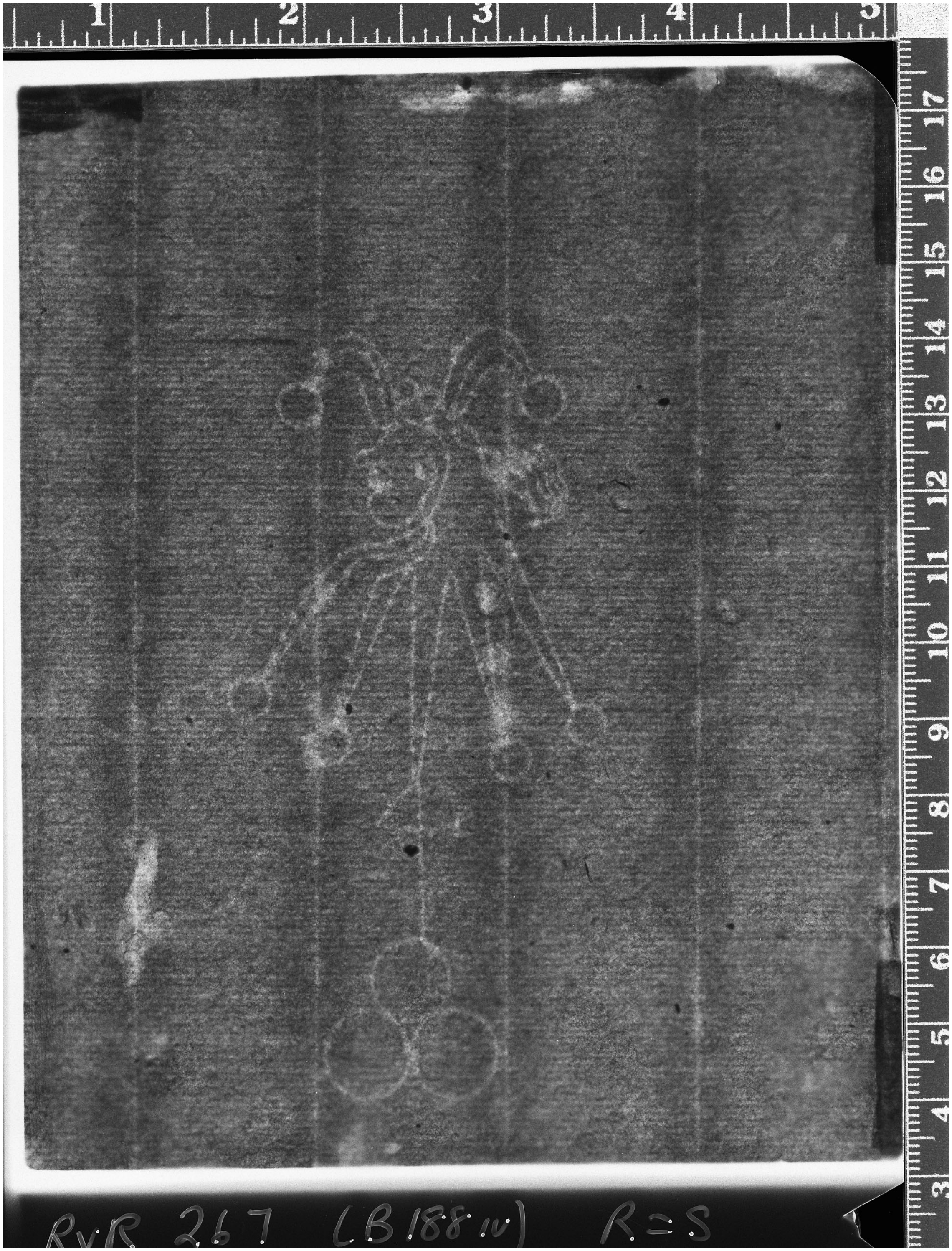

Figure 9: Beta-Radiograph of B188iv from collection of the Morgan Library & Museum

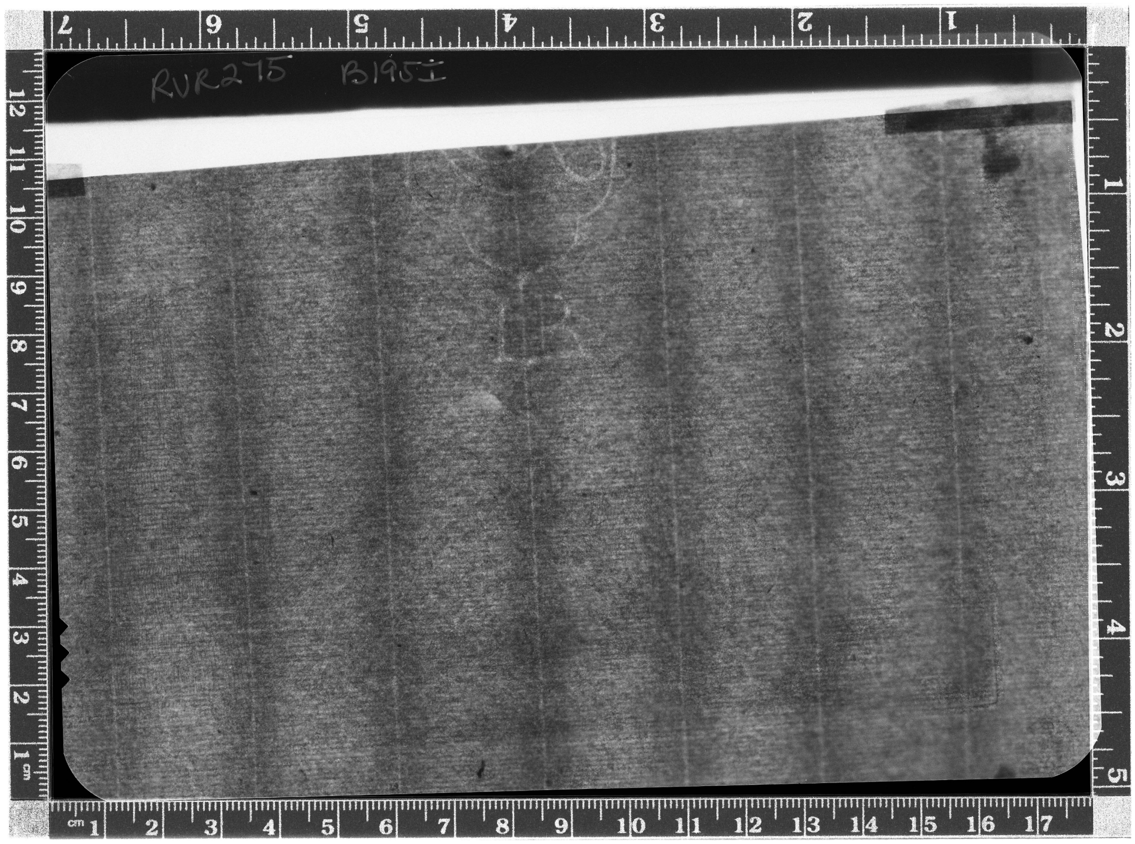

Figure 10: Beta-Radiograph of B195ii from collection of the Morgan Library & Museum

to a set of computer-assisted tools to identify mold mates from this automatically-generated short list.

The goal of this project is to create a companion to (Ash and Fletcher, 1998) as extended by (Hinterding, 2006) that catalogs the papers in Rembrandt's prints without watermarks.

Initial Issues

Full-coverage image collection

The principal initial issue is committing to full-coverage beta-radiograph collection for Rembrandt's prints. Beta-radiographs are not routinely collected to cover the full print of sizes larger than the "standard" size of approximately 4 x 5 inches. Indeed, beta-radiographs of Rembrandt's prints are commonly only collected one per print of the approximately 4 x 5 inch area around a watermark. This implies that to collect full coverage beta-radiographs of all prints by Rembrandt in the collections of the Morgan Library & Museum and the Rijskmuseum will require an extensive imaging campaign of substantial cost both in materials and human time.

Chain spacing sequence length (in)adequacy

For a chain line spacing sequence match to imply with confidence the discovery of a mold matching pair, the number of matching terms needs to include several chain spaces. As the chain spaces are commonly rather close to 25 mm, finding one spacing in one print that has a nearly exact match in another is quite possible without the two prints being mold-mates. Finding an adjacent pair of spacings in one print that matches an adjacent pair in another is also still quite likely without there being a mold match. As the earlier experiment indicates, matching triples need not indicate mold matches. However, as the number of adjacent chain spaces that match increases, the likelihood of false mold matches drops. For a print to have n chain spaces between $n+1$ chain lines, the dimension of the print perpendicular to the chain lines needs to be more than n times the typical spacing of 25 mm or 1 inch. The size of many Rembrandts prints is such that $n \leq 5$. Only a small fraction of Rembrandt's prints are larger in size than a standard 8.5 x 11 inch sheet of modern writing paper such that n could exceed 10.

Features in addition to chainspacing

While a large enough group of top-ranked chainspace matches could reveal all mold mates after visual inspection, including additional features, such as average laid line density as in (Staalduinen, 2010), may substantially reduce the number of top-ranked chainspace matches that need to be checked visually. The estimation of laid line densities requires sufficient image clarity and resolution.

Performance questions

A few of the "technical" procedure performance questions that arise:

- Can matches in chain patterns – assuming straight lines so edge intersection coordinates are sufficient to fully describe the patterns – alone produce sufficiently high rankings for mold mates that are then readily identified by visual inspection of the top few?
- How many matching spaces are needed between two beta-radiographs to reduce the number of mold mate candidates to a level reasonable for visual inspection?
- What is the level of benefit – evaluated as higher rankings of mold mates and thus reduced human examination time – of forming chainspacing sequences measured across the image along lines 2 cm or so apart, similarly to the feature matrix in (Staalduinen, 2010)?
- What distance measure is best in comparing two feature vectors/matrices?
- How accurate are different automatic methods in tracing the pattern of chain lines?
- What is the level of benefit of added features, such as the pattern of average laid line densities used by (Staalduinen, 2010) or the relative angle between straight line segments of neighboring chain lines?
- How are triples with bent chain lines best incorporated into this procedure?

A Way Forward

The data currently available from the Morgan Museum & Library and the Rijksmuseum is in the form of high resolution scans of images made primarily to record watermarks and the immediately surrounding area in the prints of Rembrandt. To motivate and target the costly and time-consuming process of collecting full-sheet beta-radiographs of all of Rembrandt's prints in the museum's collections, which we anticipate requiring, initially we will hunt for chain line pattern matches among these images containing watermarks that encompass at least 4 chain lines. The images being provided by the Rijksmuseum are from two clusters in time that are considered likely to include mold mates. the image list of the 92 from the Morgan Library & Museum (in the appendix of this document) span a wide range of Bartsch numbers from B21 to B368. In the initial phase of this project, chain spacing data will be collected by computer-assisted image marking by humans. The presence of matching or different watermarks in a pair compared only in terms of their chainspacing will be used to ascertain the success of the chain line pattern matching in distinguishing pairs of papers that are mold mates from pairs that are not.

The insights gained from beta-radiographs that just sample only a fraction of an entire print will allow us to design a limited database of full-sheet images chosen to help probe the performance of (semi-) automated mold mate identification. This will limit the number of full-sheet beta-radiographs to be collected in order to provide a persuasive proof-of-concept test. Studies on this limited full-sheet database should lead to a standardization of the data acquisition and (semi-) automated processing procedures that will be used on the Rembrandt prints in the collections of the Morgan Library & Museum and the Rijksmuseum to develop a companion volume to (Ash and Fletcher, 1998) and (Hinterding, 2008).

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Appendix: Images from Morgan Library & Museum

The registration numbers of the 92 images of watermarks used in the experiment revealing RvR153/B96 and RvR232/B157i as mold mates are listed below. The first 8 are not from prints by Rembrandt. The RvR numbers are image identifiers of Rembrandt's prints unique to the Morgan Library & Museum. The B number following the RvR number is usually the Bartsch number widely used to identify Rembrandt's prints. RVR 258 B16 Beta.tif appears to be an exception, as the image shows B176 written on the beta-radiograph. RvR 235 B1 Beta.tif apppears to be another exception.

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1968.6 part 2 de Bisschop mark.jpg
1974.69  Asseljin.jpg
1978.26 Chimenti.jpg
1980.9 Watteau.jpg
MA2380_David_WM_Beta,1808.tif
MA2382_Coypel1696_CWM_Beta.tif
MA2382_Coypel1696_WM_Beta.tif
MA3092_Grignon 1734_CWM_Beta.tif
RVR 25 B21  Beta.tif
RVR 65 B44 Beta.tif
RVR 66 B45Beta.tif
RVR 77 B49ii Beta.tif
RVR 83 B53Beta.tif
RVR 84 B53v Beta.tif
RVR 88 B561vBeta.tif
RVR 89 B56viBeta.tif
RVR 96 B63Beta.tif
RVR 100 B65iBeta.tif
RVR 108 B70iii Beta.tif
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RVR 109 B70iiiBeta.tif
RVR 110 B71vBeta.tif
RVR 113 B73ixBeta.tif
RVR 115 B74Beta.tif
RVR 115 B74C Beta.tif
RVR 119 B76Beta.tif
RVR 119 B76Countermk Beta.tif
RVR 120 B77 Beta.tif
RVR 121 B77iii Beta.tif
RVR 122 B78ii Beta.tif
RVR 123 B78ii Beta.tif
RVR 134 B86ii Beta.tif
RVR 135 B86iii Beta.tif
RvR 135-B86iii-watermark.tif
RVR 136 B86iv Beta.tif
RvR 136-B86iv-WM .tif
RVR 139 B88 Beta.tif
RVR 141 B90I Beta.tif
RVR 145 B92ii Beta.tif
RVR 147 B93iii Beta.tif
RVR 148 B49iv Beta.tif
RVR 149 B94iii Beta.tif
RVR 150 B94ii Beta.tif
RVR 152 B96 Beta.tif
RVR 153 B96 Beta.tif
RVR 156 B99 Beta.tif
RVR 164 B103ii Beta.tif
RVR 166 B104 Beta.tif
RvR 166-b104II-watermark.tif
RVR 167 B105i Beta.tif
RVR 168 B108i Beta.tif
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RVR 177 B112 Beta.tif
RVR 178 B112iv Beta.tif
RVR 180 B114i CtrMk Beta.tif
RVR 180 B114i WM Beta.tif
RVR 181 B115 Beta.tif
RVR 183 B117ii Beta.tif
RVR 184 B118ii Beta.tif
RVR 188 B121 Beta.tif
RVR 196 B127ii Beta.tif
RVR 214 B137 Beta.tif
RvR 226_B147 WM_Beta.tif
RVR 232 B157i Beta.tif
RVR 235 B1 Beta.tif
RvR 235-B159ii-Beta.tif
RVR 236 B162 Beta.tif

RVR 249 B Beta.tif
RVR 250 Beta .tif
RVR 251Beta.tif
RVR 258 B16 Beta.tif
RVR 264 B186ii Beta.tif
RVR 266 B188ii Beta.tif
RVR 267 B188iv Beta.tif
RVR 270 B192 Beta.tif
RVR 270-B192-Beta.tif
RVR 273 B194i Beta.tif
RVR 275 B195i Beta.tif
RVR 276 B195ii Beta.tif
RVR 280 B197vii Beta.tif
RVR 288 B Beta.tif
RVR 292 Beta.tif
RVR 294 B208iii Beta.tif
RVR 296 Beta.tif
RVR 297 Beta.tif
RvR 297-B211ii-Beta.tif
RvR 338 B248 Beta.tif
RvR 455_B 341 Beta.tif
RvR 459_B344 Beta.tif
RvR 481_B367WM_Beta.tif
RVR 1984.66 B74Beta.tif
RvR_031-B23-WM.tif
RvR482_B368 WM_Beta.tif