X-Radiography using portable and scanning XRF Analyzers

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Objective

Handheld X-ray fluorescence (HH-XRF) spectrometers have become an essential analytical tool for conservation. Our goal is to provide a method to perform X-radiography using HH-XRF off-site as well as for facilities that do not have traditional x-ray or beta radiography capacities.

To do this it was necessary to:

1. Determine the x-ray beam spreading angle to predict the required SID (sensor to image plate distance) for a desired irradiation diameter.
2. Confirm the intensity attenuation following the invert square law to calculate exposure perimeters.

A Bruker Tracer 5i was used for the testing. The spectrometer has a 4W tube with a voltage range of 5 – 50 kV. The collimator was removed to increase beam size. The instrument was mounted at a 45° angle to match the tube geometry and improve the shape of the beam. The sample was placed in front of the image plate. (Figure 1).

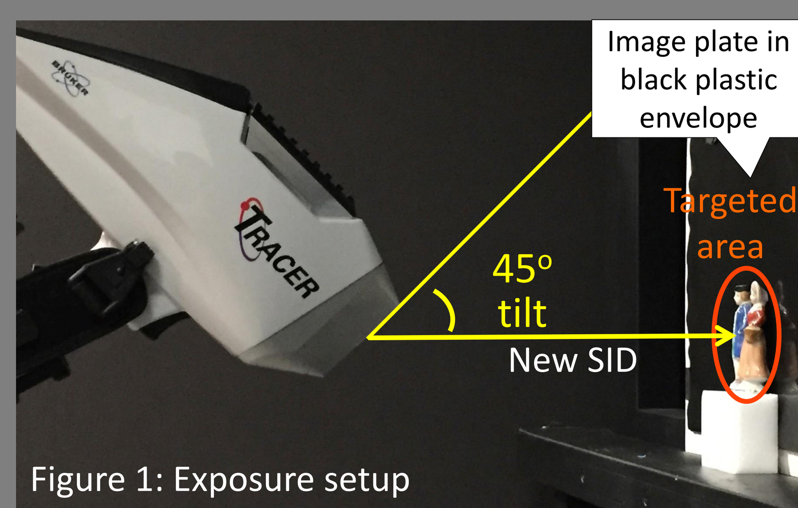

Figure 1: Exposure setup

Obtain Beam Spreading Angle

Six exposures were taken with SID set at 50, 100, 150, 200, 300, and 400mm providing the raw data required to compute both the irradiation diameter and the exposure parameters. Each exposure was run using the same experimental settings: 40kV, 25µA, and 30 sec exposure. (Figure 2). With adjacent (SID) and opposite (radius) known, the beam spread angle (**θ**) was calculated (Table 1).

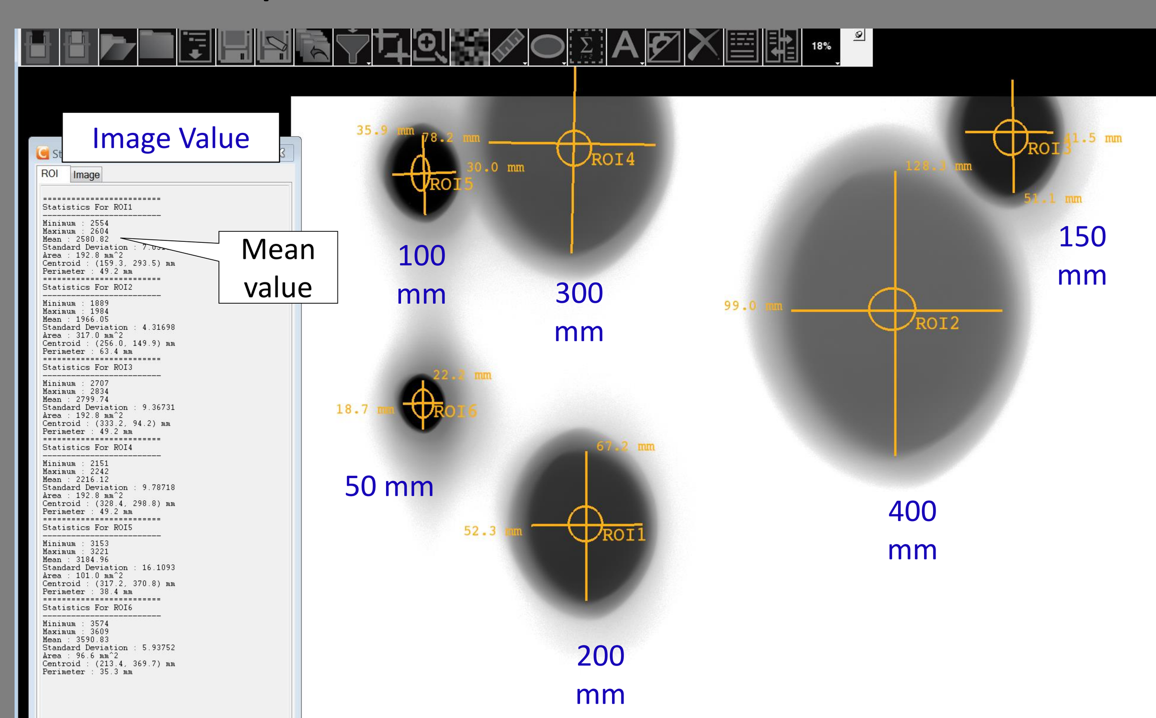

Figure 2: Screen shot of the test plate processed with CareStream's Industrex software, showing the calculated diameters of the exposed areas and the image value of each exposure.

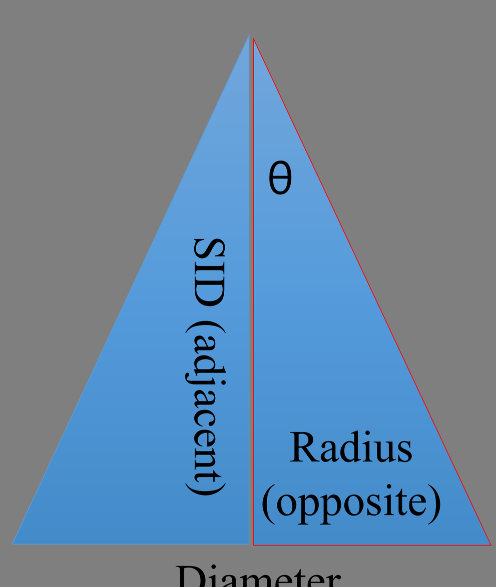

Figure 3: schematic of an x-ray beam cone, showing the trigonometrical relationship between beam spread angle, SID, and radius.

exp	SID (adjacent) mm	Diameter mm	Radius (opposite) mm	Calculated Tan θ	Beam spread angle
1	50	18.7	9.35	1.87	10.59
2	100	30	15	1.5	8.53
3	150	41.5	20.75	1.38	7.86
4	200	52.3	26.15	1.31	7.46
5	300	78.2	39.1	1.30	7.40
6	400	99	49.5	1.24	7.05

Table 1: Measured diameter and the computed beam spread angle for all six exposures.

Estimate SID to irradiate a specific size

7 degree was determined to be the best beam spread angle. Knowing that **tan θ = opposite/adjacent**, one can estimate SID or irradiation circle. Whereas tan θ = tan (7) = 0.123. Thus;

Formula 1: SID = radius/0.123

Confirm Predictable Intensity Attenuation as SID changes

The measured image value is very close to the predicted value using invert square law, see Table 2. Thus, the following formula can be used to recalculate the total exposure based on SID changes.

Formula 2: New µAs = original µAs x (new SID)^2/(original SID)^2

exp	SID (mm)	Measured Image Value (mean)	Measured difference in value as SID doubled	Estimated value difference as SID doubled	Predicted image value based on estimation (the column to the left)
1	50	3591.83	-------	------	------
2	100	3184.96	-406.87	-600*	2991.83
3	150	2799.74	-------	------	------
4	200	2580.82	-604.14	-600	2584.96
5	300	2216.12	-583.62	-600	2199.74
6	400	1966.02	-614.8	-600	1980.82

Table 2: Measured mean value v.s. Predicted mean value.

* If the x-ray intensity is attenuated according to the invert square law, as the SID doubles, the intensity reduces to a quarter. That equates to a two-stop decrease in total exposure. Each stop of exposure is about 300 in image value. Two stops result in 600 image value difference.

Test Shots

The following artifacts of different kV requirement were successfully radiographed with just one exposure using the two formulas highlighted in white.

Artifact A: miniature porcelain dolls

Exposure Perimeter

- Targeted diameter: 9 cm
- Required SID: 36.6 cm
- Energy: 50kV
- New µAs: 41493
  - µA: 35
  - Time: 1185 sec

Figure 4: miniature porcelain, 7 cm high; far left: visible light; left: radiograph.

Artifact B: Watermark in paper

Exposure Perimeter

- Targeted diameter: 9.5 cm
- Required SID: 38 cm
- Energy: 7kV
- New µAs: 936,000
  - µA: 195
  - Time: 80 minutes

Figure 5: An 11-cm section of a written document containing watermark. Left, visible light; middle: transmitted light; right: radiograph. The circled area is where the watermark is and not discernable with transmitted light.

Radiograph and Elemental Mapping of Painting on Canvas with M6-XRF

We also explored the option of using the M6 Jetstream for combined radiography and elemental mapping. The scan was taken at 30 kV 680uA with a beam size of 540um at 400ms/pixel at a scan rate of 1.4mm/s.

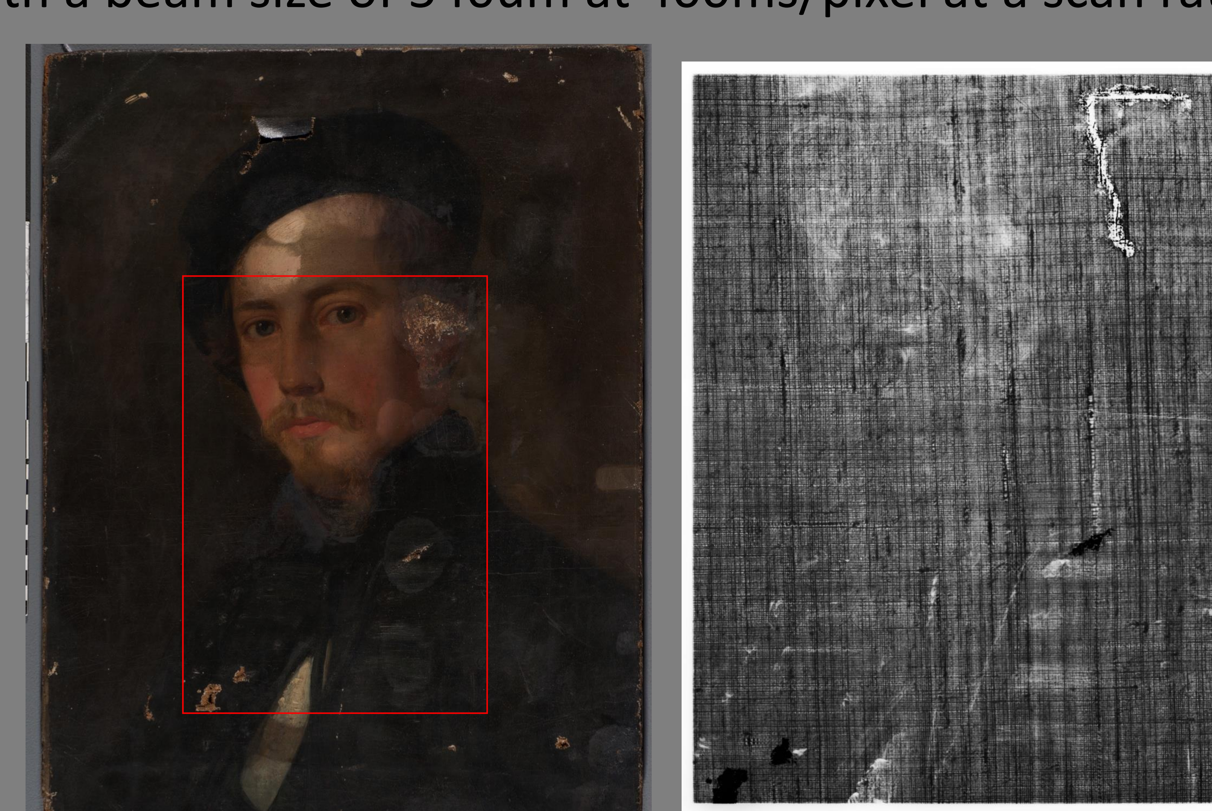

Figure 6: Oil painting on canvas, 15 ½ x 20 inches. Far left, visible light, overall; left, radiograph, exposure with M6-XRF. The red box highlights the area scanned.

Conclusion

Based on the data collected and test samples run, handheld XRF can be used to take X-radiographs of a wide range of materials. In addition, the M6 can be used to combine radiography with elemental mapping.

List of materials that can be radiographed:

- Textile
- Basketry
- Leather & parchment (up to ¼" thick)
- Plain wood (up to 4" thick)
- Painted wood & polychrome (up to 2" thick)
- Paper
- Lacquered wood (up to ½" thick)
- Painting on canvas
- Painting on wood panel (up to 2" thick)
- Bone & ivory (up to ¼" thick)
- Ceramics, clay, plaster (up to 1/8" thick)

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