On the matter of size and distance measurements in digital mammography
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Radiologists reading mammograms have a need to measure size and distance in order to estimate interval change in the size of lesions and to describe and correlate the location of lesions.

Both film-screen and digital projection radiography mammography share the same issues that result from the geometry of a diverging x-ray beam and the thickness of the compressed breast, which limited the accuracy with which image-derived measurements approximate actual physical size or distance.

Measurements from full field digital mammograms suffer the additional complication of variations in the geometry of the detector compared to an ordinary film-screen cassette, the manner in which this is described in the DICOM image header, and the manner in which display devices make use of the information in the header.
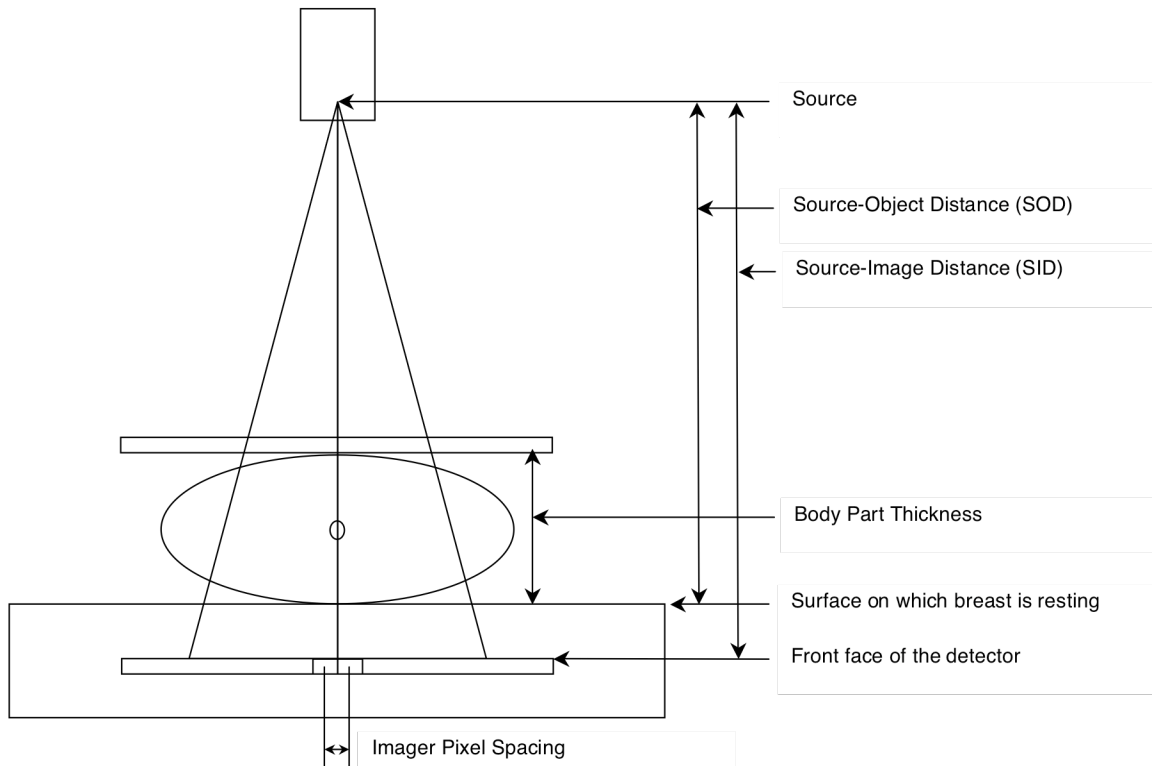
In this paper, both sets of issues will be described, to provide guidance to workstation users with respect to what realistic level of accuracy they can expect, and workstation designers in terms of what features are required by the users.

Basic geometry and DICOM definitions

For the purposes of discussion, the x-ray geometry of a full-field mammography acquisition system shall be defined to consist of:
- An x-ray source that shall be assumed to be a point source (infinitely small), in that the size of the focal spot does not significantly alter the discussion
- A distance from the x-ray source to the detector (Source Image Distance or SID), which is relatively short compared to other projection radiography modalities and hence is a significant factor, typically of the order of 650 mm
- A body part, the compressed breast, which is thick relative to the SID and hence a significant factor, typically of the order of 30 to 80 mm

This is illustrated in the frontal plane as follows:

Source

Source-Object Distance (SOD)

Source-Image Distance (SID)

Body Part Thickness

Surface on which breast is resting

Front face of the detector
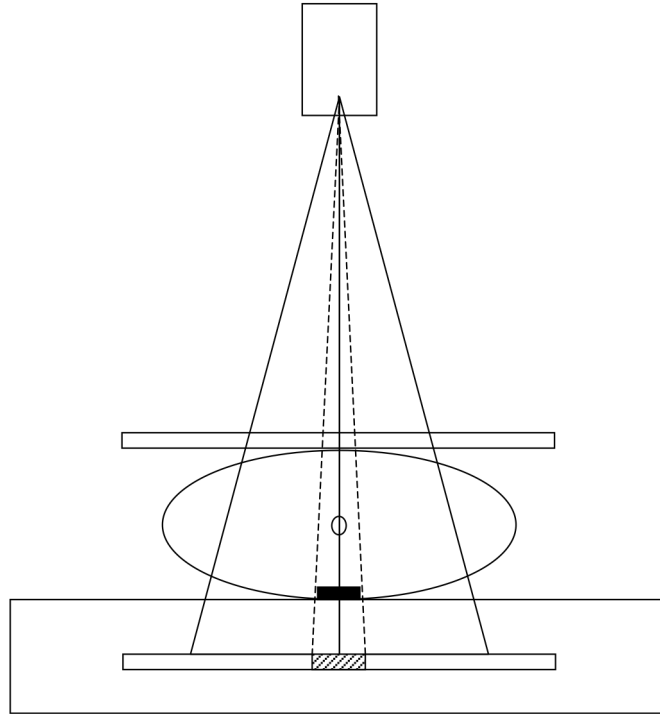
Imager Pixel Spacing

Note the following with respect to the corresponding definitions in the DICOM standard:
- Imager Pixel Spacing is defined in the standard to be the distance between the pixels encoded in the image at the *front plane of the detector housing*
- SID is encoded in DICOM as the Distance Source to Detector
- SOD is encoded in DICOM as the Distance Source to Patient and is defined as from the source to *the table, support or bucky side that is closest to* the subject
- Estimated Radiographic Magnification Factor in DICOM is defined to be the ratio of SID to SOD
- If there is no gap between the front face of the detector and the surface on which the breast is supported, then SID and SOD would be equal, Estimated Geometric Magnification Factor would be unity

Whilst it may seem counter-intuitive to define the "object" with respect to the SOD as being the support surface, which is only one side of the body part, this definition is chosen to be consistent with other types of projection radiography in which less is known about the thickness of the object. A mammography gantry has the advantage that the body part thickness may actually be known, since there is a compression plate, and this potentially allows for additional corrections as will be discussed later.

Basic measurement task – central ray and on the support surface

Suppose that our first task is to measure the size of an object that is on the surface on which the breast is resting, is centered on the central ray, and has negligible thickness and negligible size. This is shown graphically as follows:

In this scenario, the image of the object is projected onto the front face of the detector in which Imager Pixel Spacing is defined, and so a size measurement based on this parameter alone will be an overestimate, by a magnification factor proportional to the ratio between the SID and SOD. Hence a more accurate measurement would be obtained by correcting the Imager Pixel Spacing by the Estimated Radiographic Magnification Factor.

If the manufacturer is compliant in their encoding of Imager Pixel Spacing and Estimated Radiographic Magnification Factor, and both these parameters are used to make a measurement, then another measurement made for another image of the same object by a different manufacturer with different geometry should be comparable. That is, even if the absolute values of both SID and SOD change, or if the difference between them changes, the combination of Imager Pixel Spacing and Estimated Radiographic Magnification Factor will result in the same value. Even if the manufacturer defines the front face of their image detector to be the support surface, that is, SID and SOD are equal and hence Estimated Radiographic Magnification Factor is unity, then the same result will be obtained, *as long as Imager Pixel Spacing and Estimated Radiographic Magnification Factor are defined consistent with each other AND applied by the measuring device*. The following figures are exaggerated examples of these scenarios.
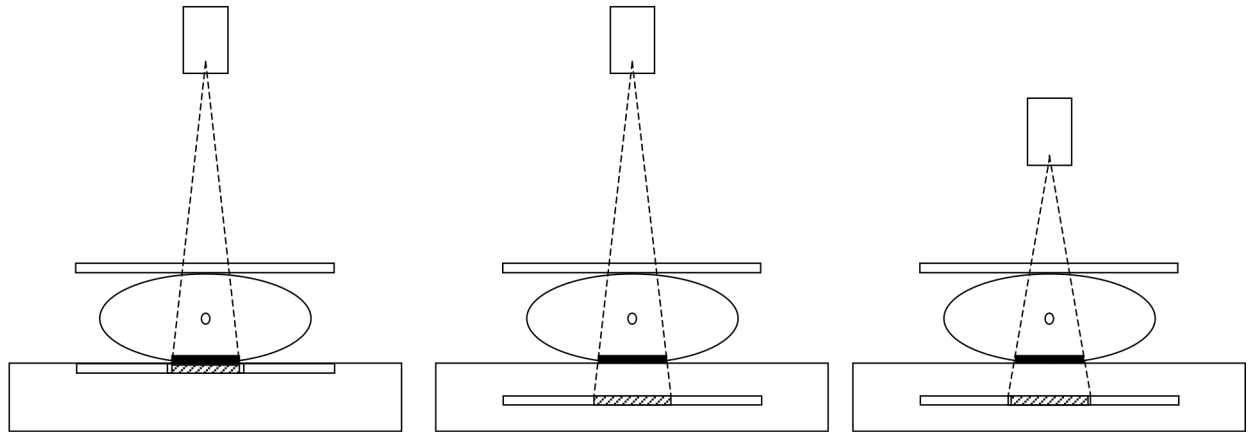
However, if as is relatively common practice in general purpose projection radiography workstations and PACS, the pixel spacing value is not corrected, then noticeable differences in measurements for the same size object will be obtained. In practice these differences have been observed to be of the order of 3 to 5% for full field views.

It is also an unfortunate aspect of the installed base of FFDM devices, that in many cases:

- Vendors differ in the manner in which they define Imager Pixel Spacing, in the sense that the difference between SID and SOD varies, with some vendors specifying no gap, and other vendors specifying a gap of a fixed size
- Neither the SID and SOD nor Estimated Radiographic Magnification Factor are encoded in the image header for later use

The DICOM standard allows sufficient flexibility in the definition and sufficient optionality in the parameters that are required to be sent that differing implementations may be compliant, yet incompatible when it comes to making a size measurement. It is for these reasons that the IHE Mammography profile calls attention to the importance of both transmitting the Estimated Radiographic Magnification Factor in images by the acquisition device, and applying it in the display device, and mandates both for compliance.

Note however, that if a manufacturer were to encode Imager Pixel Spacing and Estimated Radiographic Magnification Factor (or Distance Source to Patient and Distance Source to Detector) in a manner inconsistent with the definition in the DICOM standard, then the workstation would not be able to display comparable measurements. Specifically, if the Estimated Radiographic Magnification Factor claimed to be unity but the Imager Pixel Spacing was defined in a plane other than that of the support surface, or the Estimated Radiographic Magnification Factor claimed to be other than unity but had already been factored in to the Imager Pixel Spacing, then the "corrected" measurement would be incorrect.

In short, unless:
- Acquisition devices send both Imager Pixel Spacing and Estimated Radiographic Magnification Factor and they are consistent with each other
- Display devices apply both Imager Pixel Spacing and Estimated Radiographic Magnification Factor

the user cannot measure to within greater than a 3 to 5% accuracy, all other factors being equal.

Measuring objects not in the same plane

Consider the scenario in which the same lesion, though located in the breast along the central ray, is at different depths due to different breast compression on current and prior mammograms, as illustrated in the following figure:
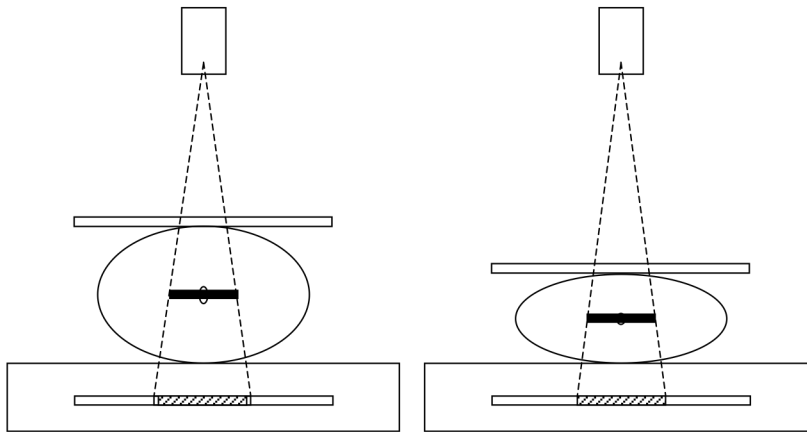
Since the object of interest is not on the support surface in this case, a revised estimate of the Source-Object Distance needs to be made. Let us define the depth of the object as a fraction of the breast thickness from 0 to 1, with 0 corresponding to the support surface.

Then the actual Source-Object Distance SOD_{Actual} as opposed to that specified in the image header $SOD_{Specified}$ can be computed as:

$$SOD_{Actual} = SOD_{Specified} - (Thickness * depth)$$

The geometric magnification factor with which to correct the specified the Imager Pixel Spacing is then:

$$Magnification = SID / (SOD_{Specified} - (Thickness * depth))$$

The relative change from prior exam to current, assuming the same gantry geometry and that the proportional depth remains the same, is independent of SID and is:

$$(SOD_{Specified} - (Thickness_{Prior} * depth)) / (SOD_{Specified} - (Thickness_{Current} * depth))$$

For example, for an object centered in the breast (depth = 0.5), an SOD of 650 mm, and a compressed breast (body part) thickness that is 25 mm on one occasion and 50 mm on the next, the relative change is:

$$(650 - 25 * 0.5) / (650 - 50 * 0.5) = 637.5 / 625 = 1.02$$

or in other words, a 2% difference in size. If the lesion were on the skin, as far from the support as possible, the difference would be just over 4% for this example.

Conclusion

The purpose of the foregoing is not to belabor the geometry of the diverging x-ray beam nor specifically to emphasize the importance of consistency of technique and positioning for successive examinations, but rather to illustrate that measurements derived from images are only an approximation of actual physical size, and that the relative error due to differences of interpretation or encoding of DICOM size-related attributes is comparable to the difference due to other factors, such as variation in breast thickness or positioning.

Accordingly, radiologists are warned not to assume excessive accuracy when assessing interval change or position based on such measurements, particularly when operator technique of device manufacturer has varied between examinations, and to be attentive to annotated information, such as compression force and body part thickness when making comparisons.