Lossless Compression of Breast Tomosynthesis Objects

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Maximize DICOM Transmission Speed and Review Performance and Minimize Storage Space

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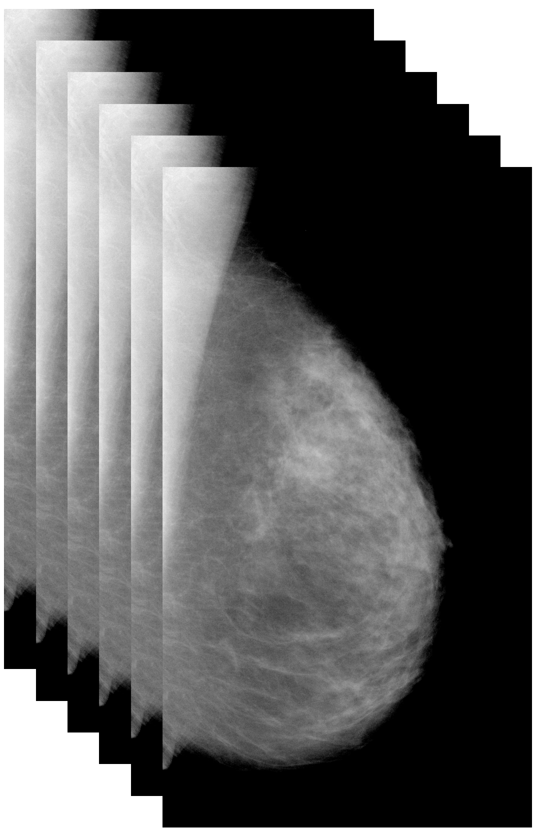
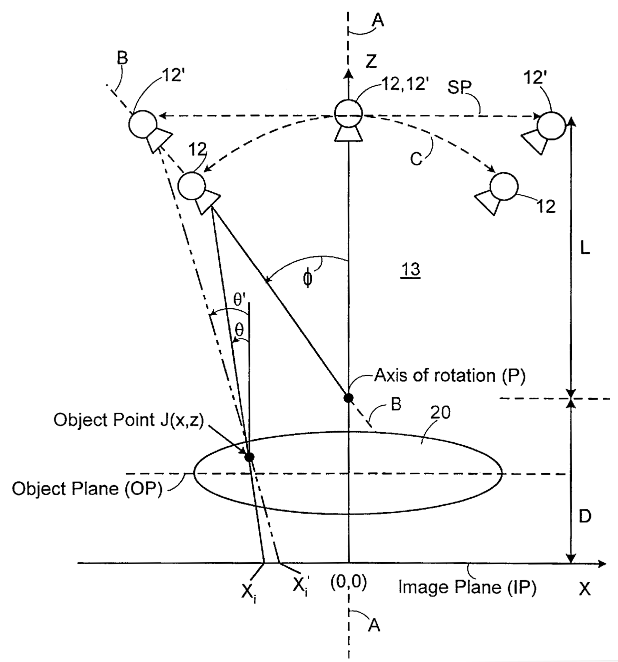
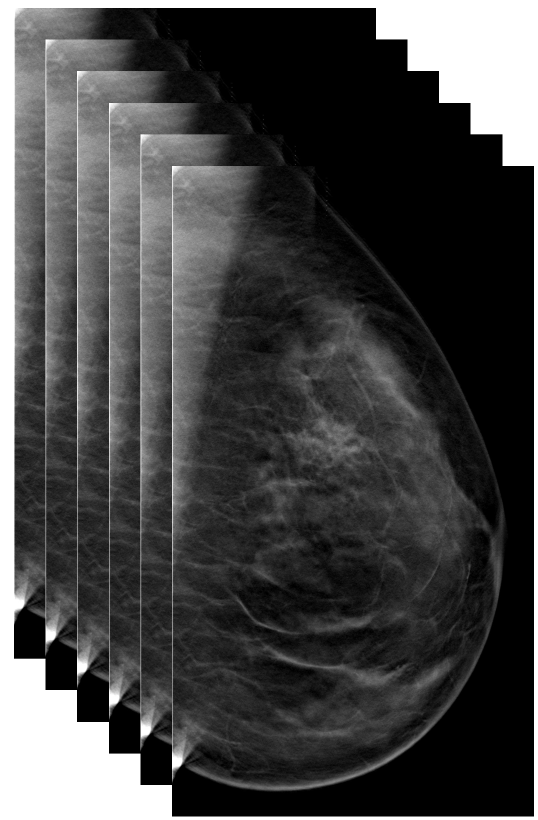
What is Breast Tomosynthesis ?

- **Multiple digital projection images acquired**
- **Reconstructed to produce “slices”**





From US Patent 5,872,828



Why is Compression Critical?

- **FFDM images are large enough**
- **Breast Tomo images are huge**
  - large matrix & high resolution (2 – 2.5 MP)
  - many slices, typically 50 – 100 per view
  - typically about 0.4 GB per image
  - 1 or 2 views per each of 2 breasts
  - i.e., 1 – 1.5 GB per study uncompressed
- **Screening reads are performed rapidly**
- **High throughput**
- **Significant stress on infrastructure**

Why Compress?

- **Faster to transmit**
  - especially if stored that way on server
- **Faster to load**
  - especially if use simple, fast to decompress, method
- **Less space**
  - reduction in size in cache, archive, backups
- **If lossless, why not?**
  - takes time & resources to compress & decompress
  - interoperability issue (unusual/non-standard scheme)

No Lossy Compression

- **FDA MQSA regulations**
  - require uncompressed or losslessly compressed images for interpretation & record keeping
  - lossy compressed images can only be used as priors for comparison
  - currently there is no exception for tomography – assume the same as any other form of FFDM
- **ACR Mammo Accreditation Program Requirements**
  - reiterate same principles as MQSA regulations
- **ACR–AAPM–SIIM Practice Guidelines for Determinants of Image Quality in Digital Mammography**

Standard Lossless Schemes

- **Image-specific**
  - *Lossless JPEG* (ISO 10918-1) ("original")
    (tested only selection value 1, as commonly used)
  - *JPEG-LS* (ISO 14495-1) (Mars rovers)
  - *JPEG 2000* (reversible) (ISO 15444-1)
- **Generic (any "file")**
  - Unix "*compress*"
  - *gzip* ("deflate", same as "zip")
  - *bzip2* (most effective but much slower)
  - tested both little and big endian word byte orders

Past Experience

- **Previous extensive comparison of generic & image-specific lossless schemes**
  - Clunie SPIE MI 2000
  - single frame images from multiple modalities, including FFDM
  - *JPEG-LS* & *JPEG 2000* outperform others and are comparable
  - traditional *lossless JPEG* does poorly
  - *bzip2* does surprisingly well
- **Benefit of *JPEG 2000* multi-component (“3D”) transform**
  - Tzannes, Aware, White Paper 2003
  - cross-sectional images (CT and MR)
  - using ISO 15444-2 Annex J (transform, no 3D rate allocation)

Tomography differences

- **FFDM is single frame**
- **Tomography is multi-slice**
  - each frame can be treated independently
  - expectation that adjacent slices are correlated
  - may benefit from 3D approaches
  - so also test JPEG 2000 multi-component extensions
- **Like FFDM, lots of background**
  - curved breast in rectangular field
  - not explicitly identified as such (and even air is noisy)
  - some schemes may take advantage of this

Methods

- **For image-specific schemes**
  - simulate encoding as DICOM multi-frame object
  - compressed with Transfer Syntax being tested
  - sum the sizes of per-frame compressed data
- **For generic schemes**
  - compress entire set of frames concatenated as a whole (simulates DICOM Deflate Transfer Syntax)
  - also test bzip2 on each frame separately & sum
  - compare little endian versus big endian order, since generic schemes are byte-oriented but data is 16 bit

Methods

- **Measure effect on pixel data only**
  - ignore DICOM header, very small relative to total
- **Describe compressed result**
  - size in number of bytes
  - bit rate (number of bits per pixel)
- **Measure compression ratio (CR) as**
  - original (all 16) bits to compressed bit rate
  - original (used) bits to compressed bit rate
  - bit rate to zero-order entropy (cumulative probability of unique symbols ignoring context – crude measure of the amount of "information" in the image)

Results

- **Will report CR of all 16 bits to compressed bit rate**
  - this is most representative of real-life performance of uncompressed DICOM file versus compressed DICOM file
  - be aware that it "exaggerates" compression ratio compared to comparison against bits used (e.g. 16/4 = 4, cf.12/4 = 3)
  - ranking of results is identical regardless of metric
  - all comparisons significantly different (p<<0.05 by paired t-test and Wilcoxon signed rank test), except those between *compress* and *gzip* using same byte order
- **Analyzed N = 25 images**
  - from 8 different subjects
- **Zero-order entropy of entire set is 5.80 ± 1.16**
  - hence expect all schemes to perform better than 16/5.80 = 2.76

Compression Ratios by Scheme

Scheme	CR mean	CR SD
gzip little endian	3.11	0.70
gzip big endian	3.11	0.70
compress little endian	3.11	0.80
compress big endian	3.11	0.80
bzip2 little endian	4.57	1.08
bzip2 big endian	4.61	1.05
bzip2 little endian per frame	4.56	1.07
JPEG lossless selection value 1	3.77	0.69
JPEG-LS	4.97	1.12
JPEG 2000 5x3 VM single frame	4.89	1.09
JPEG 2000 5x3 Aware single frame	4.90	1.09
JPEG 2000 5x3 Aware multi-component all frames	5.07	1.67
JPEG 2000 5x3 Aware multi-component 10 frame slab	5.03	1.16

Pixel Data Size in MB by Scheme

Scheme	Mean	SD
gzip little endian	148	49.3
gzip big endian	148	49.3
compress little endian	150	50.3
compress big endian	150	50.3
bzip2 little endian	101	33.6
bzip2 big endian	100	33.3
bzip2 little endian per frame	101	33.5
JPEG lossless selection value 1	120	37.4
JPEG-LS	92.8	31.2
JPEG 2000 5x3 VM single frame	94.1	31.1
JPEG 2000 5x3 Aware single frame	94.0	31.1
JPEG 2000 5x3 Aware multi-component all frames	90.9	29.8
JPEG 2000 5x3 Aware multi-component 10 frame slab	91.6	30.0
Original uncompressed pixel data	442	126

Assessment of Results

- **For single frame compression schemes**
  - *JPEG-LS* performs best (4.97), by slim margin over *JPEG 2000* (4.89 VM, 4.90 Aware)
  - the “original” *JPEG Lossless* performs relatively poorly (3.77), consistent with experience with other modalities
- **Generic compression schemes**
  - do poorly, except for *bzip2* (4.61), which out performs “original” *JPEG lossless*, is not too far from *JPEG-LS* or *JPEG 2000*, and slightly better with big endian (4.61) rather than little (4.57)
- **Multi-frame JPEG 2000**
  - does best of all (5.07), with modest (3%) improvement relative to single frame (4.90) when all frames used, most (76%) of the gain realized when 10 slices used per slab (5.03)

Conclusion

- **Results agree with experience from other modalities**
- **Using JPEG-LS, JPEG 2000 or bzip2, files can be reduced in size by just under a factor of five**
- **Given anecdotal experience that JPEG-LS is potentially faster and consumers fewer resources than JPEG 2000 or bzip2, JPEG-LS is recommended**
- **However, JPEG-LS is less widely implemented in PACS, so JPEG 2000 is good alternative**
- **The relatively small incremental benefit of multi-component (3D) probably does not justify its use, especially given lack of availability of codecs**

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