I-ImaS

Workpackage-3:

Update on current progress and report for deliverable D.8:
“Translating information signatures to a sequence of well-defined processing functions”

London, 12th – 13th October 2004
**WP3 tasks:**

**Task 3.1:** creation of an image database for medical applications

**Task 3.2:** Identification of important features to be measured by the image analysis

**Task 3.3:** Feature analysis and selection, in order to decide which features to use as feedback to the sensor system for different applications using the information from previous task

**Task 3.4:** Evaluation of operator response to the images created by using selected features as feedback to the sensors

**WP3 deliverables:**

**D.7:** An organized, searchable database of images from medical applications (Oct.2004)

**D.8:** A report on the translation of the information signatures to a sequence of well-defined processing functions (Oct.2004)

**D.9:** A report summarizing the results of evaluating the different approaches to providing intelligence in the sensor/imaging system (Dec.2004)
Organization of current work:

1. Compatibility of current image analysis source code with SIMD specification as proposed by SINTEF for sensor IC design.
2. Organized database of images in accordance to the RIEDS templates for image acquisition experiments (D.7)
3. Preliminary feature functions assessment, analysis and performance evaluation (D.8)
4. Discussions & Proposals on image acquisition experiments and clinical evaluation of image sets
5. Further work & Requirements
Current Progress Overview:

- SIMD compatibility of current feature functions
  - D.7: Organized database of images (mammoDB/RIEDS)
  - D.8: Preliminary feature functions evaluation
  - Discussions & Proposals
  - Further work & Requirements
**SIMD compatibility – Overview**

**Requirements [18-19]:**
- code should be effectively executed with multiple instances of input data (SIMD: Single-Instruction-Multiple-Data)
- process data as they arrive from line-scanning modules
- avoid branching functions ("if-then") on data streaming
- limited access to global image statistics or measurements
- provide localized data streaming & processing

**Main Advantages [18-19]:**
- Data-oriented processing on relatively independent data blocks
- Similar processing executed in parallel for various local areas
- Limited data bus traffic
- Simple hardware implementation using multiple similar IC modules
**Texture Features Calculation Procedure:**

1. Calculate each feature function for a fixed-sized box
2. Average feature values for current “column”
3. Store mean, stdev values and advance to the next “column”
4. Final result is a 1-D curve for each feature function

**Is the above procedure SIMD-compatible?**

- Processing is conducted on localized instances of data
- No branching “if-then” statements
- Limited requirements for global image statistics
- Can be implemented for on-line, single-stage processing
Maximum data storage requirement is one image “column”

2-D processing can be done in parallel by N vertically-aligned sensor IC modules

1-D processing is a simple mean, stdev of the N intermediate output values

Final “signature” is one value per “column”
Current Feature Functions: Organization & Complexity

MATLAB sample:

```matlab
function npower=func_SF19( I )
    npower = sum(sum(I.^2))/(size(I,1)*size(I,2));
```

C/C++ sample:

```c
int func_SF19( unsigned char *pixel, int boxsz )
{
    int   i, j, sum=0, px, npower;
    for ( i=0; i<boxsz; i++ )
        for ( j=0; j<boxsz; j++ )
            {
                px = *(pixel+(i-1)*boxsz+j);
                sum = sum + px*px;
            }
    npower = sum / (boxsz*boxsz);
    return(npower);
}
```
Current Feature Functions: Organization & Complexity

**x86 Assembly sample:**

```assembly
... DSEG SEGMENT

BOX_SZ DW 50
ICOUNT DW 50
JCOUNT DW 50
SUM DW 0
NPW POWER DW 0

DSEG ENDS

... FUNC_SF19 PROC

PUSHAD

MOV SUM, 0

L1: CMP JCOUNT, 0
    JNG L0

L2: CMP JCOUNT, 0
    JNG L1

MOV DI, JCOUNT

DSEGDSEG SEGMENT

BOX_SZ DWDW 50
ICOUNT DWDW 50
JCOUNT DWDW 50
SUMDWDW 0
NPOWER DWDW 0

DSEGDSEG ENDS

L0: MOV AX, BOX_SZ
    MUL AX, AX
    MOV CX, AX
    MOV AX, SUM
    DIV CX
    MOV NPOWER, CX

POPA

L1: CMP JCOUNT, 0
    JNG L0

L2: CMP JCOUNT, 0
    JNG L1

MOV DI, JCOUNT

FUNC_SF19 ENDP
```

MOV BX, ICOUNT
SUB BX, 1
MUL BX, BOX_SZ
MOV AX, PIXEL[BX][DI]
MUL AX, AX
ADD SUM, AX
SUB JCOUNT, 1
JMP L2

MOV BX, ICOUNT
MUL BX, BOX_SZ
MOV AX, PIXEL[BX][DI]
MUL AX, AX
ADD SUM, AX
SUB JCOUNT, 1
JMP L1

L0; MOV AX, BOX_SZ
    MUL AX, AX
    MOV CX, AX
    MOV AX, SUM
    DIV CX
    MOV NPOWER, CX

POPA

L1: CMP JCOUNT, 0
    JNG L0

L2: CMP JCOUNT, 0
    JNG L1

MOV DI, JCOUNT

FUNC_SF19 ENDP
```
Current Progress Overview:

✓ **SIMD compatibility of current feature functions**

➢ **D.7: Organized database of images (mammoDB/RIEDS)**
  - D.8: Preliminary feature functions evaluation
  - Discussions & Proposals
  - Further work & Requirements
Experiment Documentation

Basic Task:
- document mammographic device specifications
- document experiment settings and environment
- log experiment progress and image acquiring (samples)
- document technical aspects of image quality for each sample
- document clinical aspects of image quality for each sample

Reference Base:
- Mammographic device quality assessment reports
- List of technical aspects related to image quality (Technician’s QC)
- List of clinical aspects related to image quality (Physician’s QC)
RIEDS: Radiographic Imaging Evaluation & Documentation System [21,23]

version 1.2:

- **Form A**: X-ray Equipment Specifications Assessment
- **Form B**: Image Acquisition – Experiment Settings
- **Form C**: Image Acquisition – Experiment Logging
- **Form D**: Image Quality Evaluation – Technician’s QC
- **Form E**: Image Quality Evaluation – Physician’s QC – Mammo
- **Form F**: Image Quality Evaluation – Physician’s QC – Dental
### Form F: Image Quality Evaluation – Physician’s QC – Dental [23]

**Image Quality Properties (doctor’s grading):**

- Contrast Estimation (quality)
- Spatial Resolution Estimation (quality)
- Noise Estimation (%)
- Background / Tissue Discrimination

- Teeth Enamel and Dentine (intraoral)
- Caries Lesion (intraoral)
- Periodontal Lesions (intraoral)
- Periapical Lesions (intraoral)
- Bone (intraoral)
- Bone Lesions (intraoral)
- Soft Tissues (intraoral)
- Restoration Materials (intraoral)

- Bone (extraoral)
- Teeth (extraoral)
- Soft Tissues (extraoral)
- Sharpness (extraoral)
- Slice Thickness (extraoral)
D.7: Organized database of images (SINTEF)

- Need for electronic organization of image acquisition & evaluation
- Create a RIE DS-compatible database for image documentation
- Create electronic versions of RIE DS forms for electronic submission
- Full R-DBMS design for RIE DS data integrity & control

Proposed design:

- Use MS-Access, MS-Excel and Matlab as core platform
- Use hierarchical ID structure for unique image descriptors
- Use electronic version of RIE DS forms in MS-Excel format

Important Note:

- Data are to be collected on-site using the electronic forms
- Filled forms are to be checked later by DB administrator for correctness & integrity before entered into the current database (2-phase “commit”)

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Current Progress Overview:

- **SIMD compatibility of current feature functions**
- **D.7: Organized database of images (mammoDB/RIEDS)**
- **D.8: Preliminary feature functions evaluation**
  - Discussions & Proposals
  - Further work & Requirements
Preliminary Feature Functions Evaluation (D.8)

Basic Tasks [21]:

- Use simple textural feature functions to map image quality into quantitative measurements for sensor intelligence (feedback)
- Investigate the translation of the information signatures to a sequence of well-defined processing functions (Oct.2004)

D.8 report – Overview [23]:

- Web-based public mammographic image database (DB1)
- Experiment planning & documentation (RIEDS)
- Preliminary phantom image database (DB2)
- SimModel-1A: exposure simulation
- PredModel-1A: texture features extraction
- PredModel-1B: feature quality evaluation versus exposure
SimModel-1A: Exposure simulation

Basic Task:

- Formulate a realistic theoretical model for simulating manual exposure configurations using optimal exposure images.
- Apply simulation model in all (optimal) mammographic images to create simulated (sub-optimal) images (DB1).
- Validate simulation results (DB1) using real phantom images at various exposure configurations (DB2).
- Use base set of 20 images, generate 21 exposure simulation for each one, calculate 20 features over 3 box sizes (10, 25, 50), calculate feature mean and stdev values.

Model Design (parameters):

- Rx : Radiation Exposure
- OD : Optical Density of X-ray projected subject
- GL : Gray Value of (digital) sensors
- GI : Greylevel of pixels in the resulting image
SimModel-1A: 4-phase model implementation

**F1:**
- kVp: [25...29] , mAs: [50...200]
- Rx: [0.0128...4,000] mGy

\[ \text{Rx: } f_1(kVp,mA) = C_{1,1} \cdot \log_{10}(kVp^2 \cdot mA) + C_{1,0} \]

- \( C_{1,0} = -0.897021103 \)
- \( C_{1,1} = 0.000029114 \)

**F2:**
- Rx: [0.0128...4,000] mGy
- OD: [0.04...3.60]

\[ \text{OD: } f_2(Rx) = C_{2,1} \cdot \log_{10}(Rx) + C_{2,0} \]

- \( C_{2,0} = 2.740896827 \)
- \( C_{2,1} = 1.426939483 \)

**F3:**
- OD: [0.04 ...3.60]
- GL: [495 ...4069]

\[ \text{GL: } f_3(OD) = (OD - C_{3,0}) \cdot \frac{1}{C_{3,1}} \]

- \( C_{3,0} = 4.093060996 \)
- \( C_{3,1} = -0.000996083 \)

**F4:**
- GL: [4095 ...0]
- GI: [0 ...255]

\[ \text{GI: } F_4(GL) = C_{4,1} \cdot (GL) + C_{4,0} \]

- \( C_{4,0} = 255 \)
- \( C_{4,1} = -0.062271062 \)
**FULL SIMULATION PROCEDURE:**

1. **Input:** \( \{kVp(0), mAs(0)\}, \{\text{image}(0)_{x,y}\}, \{kVp(z), mAs(z)\} \)

2. \[ \left\{ kVp(0), mAs(0) \right\} \xrightarrow{f_1} [Rx(0)] \] 

3. \[ \left\{ \text{image}(0)_{x,y} \right\} \xrightarrow{f_4^{-1}} GL(0)_{x,y} \xrightarrow{f_5^{-1}} OD(0)_{x,y} \xrightarrow{f_7^{-1}} Rx(0)_{x,y} \]

4. \[ Rx(z)_{x,y} = \frac{Rx(0)_{x,y}}{r} \]

5. \[ Rx(z)_{x,y} \xrightarrow{f_2} GL(z)_{x,y} \xrightarrow{f_3} GI(z)_{x,y} \xrightarrow{\text{image}(z)_{x,y}} \]

6. **Output:** \( \{\text{image}(z)_{x,y}\} \)
SimModel-1A: simulation example from DB1

sim.#1: 25 kVp / 75 mAs
init: 27 kVp / 125 mAs
sim.#2: 29 kVp / 200 mAs
SimModel-1A: Validation & Verification example from DB2

Real experimental phantom images included in DB2:

- **cfg.F2**: 23 kVp / 4 mAs
- **cfg.A1**: 26 kVp / 4 mAs
- **cfg.G2**: 30 kVp / 4 mAs
**PredModel-1A: Texture Features Extraction**

**Basic Task [20]:**
- Formulate a set of content-rich textural feature function, well-suited for mammographic image analysis.
- Use only first-order statistics or functions of low computational complexity
- Apply complete set of feature functions over all the available images (real + simulated) and construct analytical profiles.

**Model Design (specifications):**
- Apply progressive image scanning on x-axis
- Average calculated feature values per scanning “column”
- Produce simple 1-D transition curves for each feature function
Min value:
\[ I_{\text{min}} = \min_{XY} \{I(x, y)\} \]

Max value:
\[ I_{\text{max}} = \max_{XY} \{I(x, y)\} \]

Mean value:
\[ \mu = \frac{1}{XY} \sum_{i=1}^{X} \sum_{j=1}^{Y} I(x, y) \]

Standard Deviation:
\[ \sigma = \sqrt{\frac{1}{(XY-1)} \sum_{i=1}^{X} \sum_{j=1}^{Y} (I(x, y) - \mu)^2} \]

Skewness:
\[ sk = \frac{1}{XY} \sum_{i=1}^{X} \sum_{j=1}^{Y} \left( \frac{I(x, y) - \mu}{\sigma} \right)^3 \]

Kurtosis:
\[ kr = \left( \frac{1}{XY} \sum_{i=1}^{X} \sum_{j=1}^{Y} \left( \frac{I(x, y) - \mu}{\sigma} \right) \right)^4 - 3 \]

Signal Power:
\[ P_{XY} = \sum_{i=1}^{X} \sum_{j=1}^{Y} \|I(x, y)\|^2 \]

Entropy:
\[ E = \sum_{k=1}^{100} P_{\text{Ghist}(k)} \cdot \log(P_{\text{Ghist}(k)}) \]

Zero-Crossings count:
\[ ZC = \sum \{k : (I_k(x, y) - \mu) \cdot (I_{k+1}(x, y) - \mu) \leq 0\} \]

Surface:
\[ S_{XY} = \sum_{i=1}^{X-1} \sum_{j=1}^{Y-1} \left( I(x, y) + 1 + \|I(x+1, y) - I(x, y)\| + \|I(x, y+1) - I(x, y)\| \right) \]
Volume:

\[ V_{XY} = \sum_{i=1}^{X} \sum_{j=1}^{Y} I(x, y) \]

Synth. Feature-12:

\[ SF_{12} = \frac{(I_{\text{max}} - I_{\text{min}})^2}{\mu} \]

Synth. Feature-13:

\[ SF_{13} = \frac{\mu - I_{\text{min}}}{I_{\text{max}} - I_{\text{min}}} \]

Synth. Feature-14:

\[ SF_{14} = \frac{\mu}{\sigma} \]

Synth. Feature-15:

\[ SF_{15} = \frac{P_{XY}}{\mu^2} \]

Synth. Feature-16:

\[ SF_{16} = \frac{S_{XY}}{3V_{XY}} \]

Synth. Feature-17:

\[ SF_{17} = \frac{S_{XY}}{XY} \]

Synth. Feature-18:

\[ SF_{18} = \frac{ZC}{XY} \]

Synth. Feature-19:

\[ SF_{19} = \frac{P_{XY}}{XY} \]

Synth. Feature-20:

\[ SF_{20} = \log\left(1 - \frac{SF_{19}}{255^2}\right) \]
**PredModel-1A: Intermediate 2-D results (example)**

**Function: F04 (STDEV) / boxsize: 10**

**sim.#1:** 25 kVp / 75 mAs  
**init:** 27 kVp / 125 mAs  
**cfg.2:** 29 kVp / 200 mAs
PredModel-1A: Intermediate 2-D results (example)

Function: SF20 (Synthetic) / boxsize: 10

**sim.#1:** 25 kVp / 75 mAs

**init:** 27 kVp / 125 mAs

**cfg.2:** 29 kVp / 200 mAs
**PredModel-1B: Texture Features Evaluation**

**Basic Task:**
- Investigate feature results from PredModel-1A.
- Identify features with smooth & consistent behavior over the entire mammographic image set.
- Identify features with smooth & consistent behavior over the entire range of exposure settings.

**Model Design (specifications):**
- Analyze feature functions behavior versus exposure.
- Conduct visual evaluation for preliminary selection.
- Investigate both exposure effects and breast tissue detection.
Topic-3: Preliminary feature functions evaluation (D.8)

Transitions vs Total Exposure
Image: mamm016 / boxsz: 10 / Feature: STDEV

Image Scanning Columns (R->L)
Feature Value

Total Exposure R=\log(mAs*\text{kV}^2)
Topic-3: Preliminary feature functions evaluation (D.8)

Transitions vs Total Exposure
Image: mamm016 / boxsz: 25 / Feature: SF20

Image Scanning Columns (R>L)

Total Exposure: $R = \log(\text{mAs} \cdot kVp^2)$

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### PredModel-1B: Feature evaluation for boxsize=10

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*London, 12-13 October 2004*
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**PredModel-1B: Preliminary Assessment**

**Best feature functions:**

- F01: “MIN”
- F02: “MAX”
- F03: “MEAN”
- F07: “POWER”
- F11: “VOLUME”
- SF19: (normalized power)
- SF20: (normalized exposure)

**Local features combination:**

- Averaging over the “column”
- Unbiased over partial results

**SIMD compatibility:**

- Segment “columns” into data blocks
- Almost entirely localized calculations

**Basic Conclusions:**

- Averaging partial feature values over “columns” produce unbiased results.
- Most feature functions can be calculated directly over the entire “column”.
- Best features relate to sums over pixel values or squared pixel values.
- Larger box sizes produce more consistent results.
- Processing complexity grows proportionally with number of pixels in the box.
- First order statistics can also be used successfully for breast tissue detection.
Current Progress Overview:

- *SIMD compatibility of current feature functions*
- *D.7: Organized database of images (mammoDB/RIEDS)*
- *D.8: Preliminary feature functions evaluation*

**Discussions & Proposals**

- Further work & Requirements
**Discussions & Proposals (WP3):**

On test phantom images from Siemens Mammomat B system (UCL):

- 127 μm resolution
- 4,5 cm standard UK compressed breast phantom
- acquired 42 images at [28...40] kVp and [5...100] mAs
- resulting images of (cropped) size 770x1440x16bit “.raw” format

**Overall quality assessment of B-phantom image sets:**

- Tissue areas are underexposed, even at very high kVp/mAs settings
- kVp settings over 30 are unrealistic for mammographic purposes
- Phantom may be too “thick” or source-detector distance too large
- Phantom should be adjusted for ranges around: [26...28] kVp, [46...168] mAs
- final images must be converted to 8-bit for display purposes (evaluation)
B-phantom test images – Overview

**cfg.1:** 28 kVp / 16 mAs

**cfg.2:** 30 kVp / 40 mAs

**cfg.3:** 35 kVp / 64 mAs

**cfg.4:** 40 kVp / 80 mAs
B-phantom test images – Signal variance outside phantom

B-phantom sample image set
Signal Variance ($\sigma^2$) estimation on extra-tissue areas (“black”)

-0.000020000
-0.000040000
-0.000060000
-0.000080000
-0.000100000

0 20 40 60 80 100 120 mAs

Var(img)

28 kVp  30 kVp  35 kVp  40 kVp
B-phantom test images – Signal variance inside phantom

Signal Variance ($\sigma^2$) estimation on intra-tissue areas ("white")

Var(img) vs. mAs for different kVp:
- 28 kVp
- 30 kVp
- 35 kVp
- 40 kVp
Exposure profiles: Patient dose vs kVp (abdomen)

Incident air kerma (solid) and entrance surface dose (dashed) for an abdomen AP radiograph on a conventional X-ray machine [11].
Exposure profiles: Patient dose vs thickness (stomach)

Relative patient effective dose for a stomach examination at various standard exposure profiles on a conventional X-ray machine [11].
The statistically expected (dashed) and true measured rms(%) noise dependence on exposure, for the GE CT/T 8800 scanner [22].
Exposure profiles: Standard AERC curves (fluoroscopic)

Standard kVp/mAs exposure profiles (AERC) for a modern fluoroscopic unit [11].
- P1: std 5 mA, P2: std 3 mA, P3: 4 mA high contrast, P4: 8 mA high contrast, P5: “paediatric”, P6: “iodine”
Discussions & Proposals (WP3):

On image evaluation procedure for available radiologists (SINTEF):

- “Can we use dual image acquisition, one with Mammomat (UCL) for image processing tasks and one with some standard digital mammographic system for clinical evaluation tasks?”
- “Can optimal exposure parameters be locally defined (by the radiologist) at various areas of the same image?”

Preliminary assessment:

- Using dual image acquisition for different tasks is risky in terms of statistical integrity, especially when display parameters vary between the two images.
- Optimal exposure evaluation in terms of clinical findings depends on combining features from the complete image. Thus, the radiologist has to evaluate the same, complete image as the textural feature functions do, using the same information content and resolution.
Discussions & Proposals (WP3):

On using synchrotron images within the current design (UoT):

- “Can we use synchrotron images as basis for the current work on image processing for sensor intelligence?”
- “If the model is adjusted so that keV is used instead of kVp and mGy instead of mAs, does the design changes radically?”

Preliminary assessment:

- Having data from multiple sources of statistically significant differences does not permit robust and sound textural analysis.
- Due to the intrinsic value of synchrotron images and the compatibility of the proposed model, further research on this area is very promising.
Current Progress Overview:

✓ SIMD compatibility of current feature functions
✓ D.7: Organized database of images (mammoDB/RIEDS)
✓ D.8: Preliminary feature functions evaluation
✓ Discussions & Proposals
➢ Further work & Requirements
Further Progress Requirements (WP3):

1. Finalize choices on mammographic/dental equipment and subjects (phantoms and tissue samples), designating optimal conditions and settings for image acquisition experiments that closely match the performance of the final system.

2. Calibrate target properties and absorption settings, in order to provide a test subject that produces realistic imaging results for operational ranges that are typically used in clinical practice, as well as a preconfigured embedded test pattern, in order to measure global signal attributes (noise%, SR, etc).

3. Perform all the necessary image acquisition experiments in order to create a new, thoroughly documented, mammographic & dental image database that will be used as a solid base for further analysis (DB3).

4. Perform extensive image quality assessment surveys for all the mammographic & dental images in the created image database (DB3), using existing RIEDS documentation templates for adding annotative clinical evaluations for all the available cases.

5. Investigate alternative approaches and levels of providing intelligence in the sensor/imaging system through the application of sophisticated image processing.
Current Progress Overview:

✓ SIMD compatibility of current feature functions
✓ D.7: Organized database of images (mammoDB/RIEDS)
✓ D.8: Preliminary feature functions evaluation
✓ Discussions & Proposals
✓ Further work & Requirements

For further details on description of work and current status, see: [21] and [23] →
Suggestive References:


