DEFENCE R&D DÉFENSE

Advanced Signal Processing for Non-Invasive Medical Diagnostic System Applications

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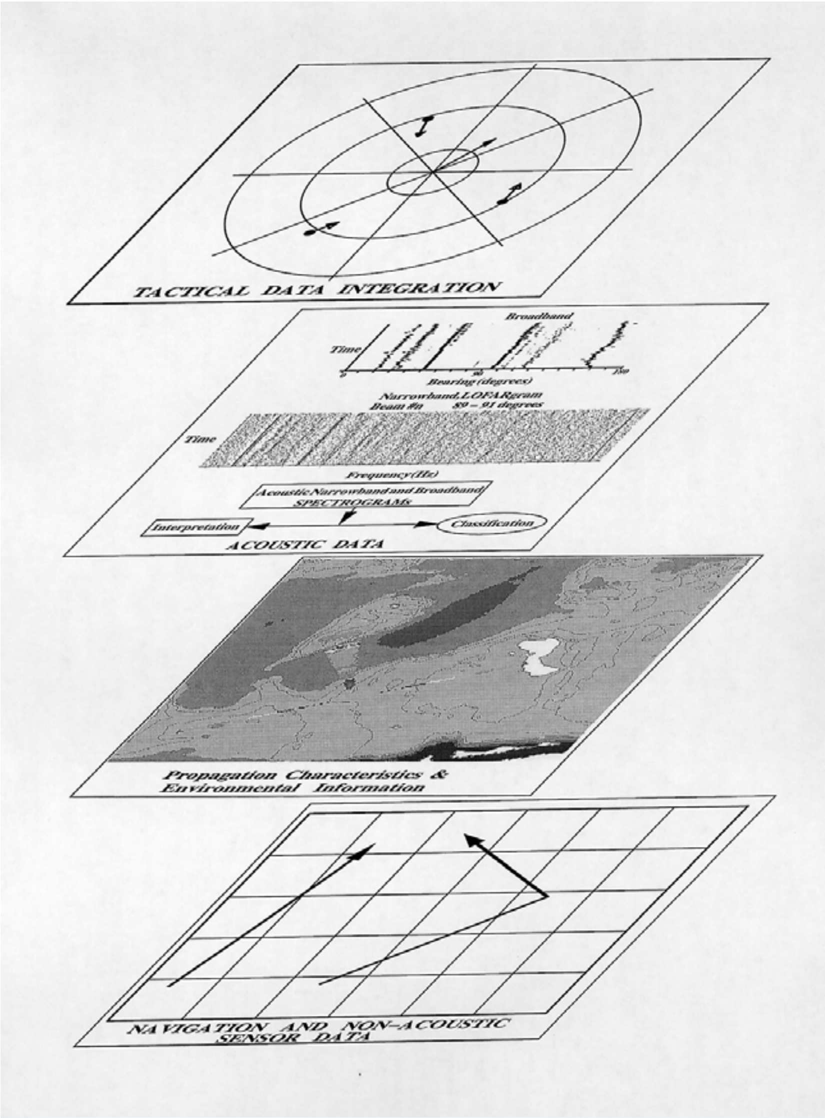
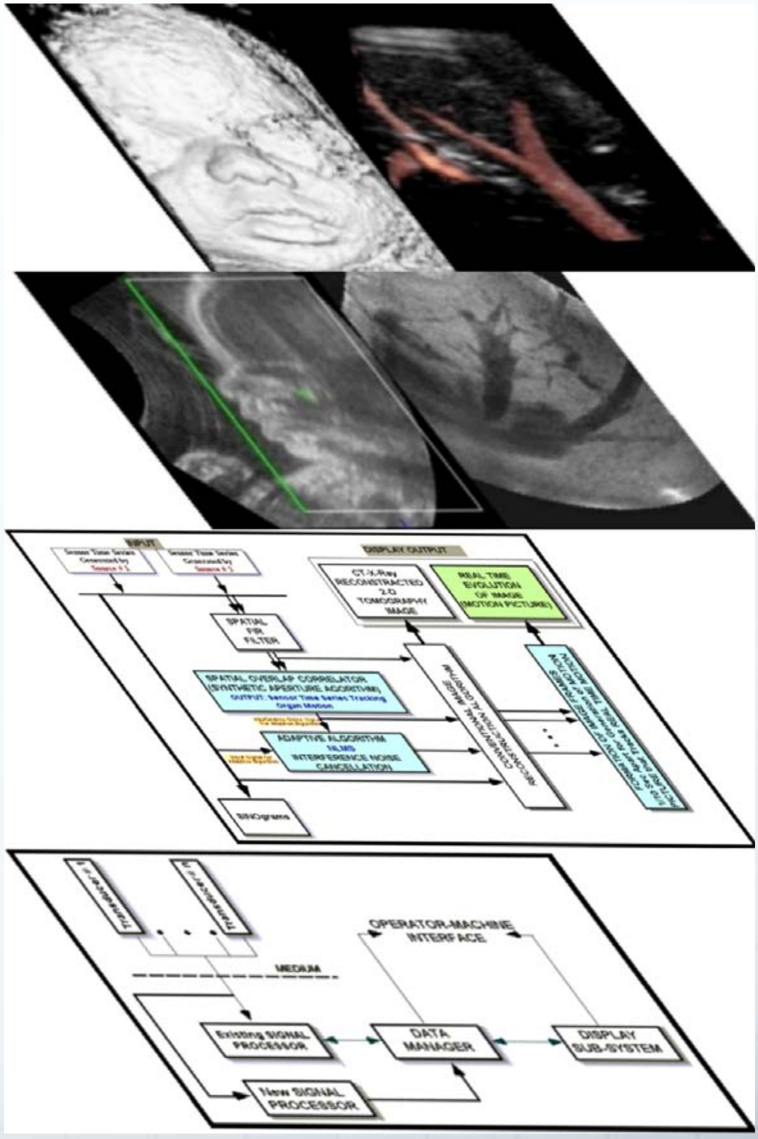
Stergios Stergiopoulos, PhD
Defence R&D Canada
Dept. of ECE, University of Toronto

Integration of Different Levels of Information for Sonar, Radar and Medical Imaging Systems





Sonar Operations

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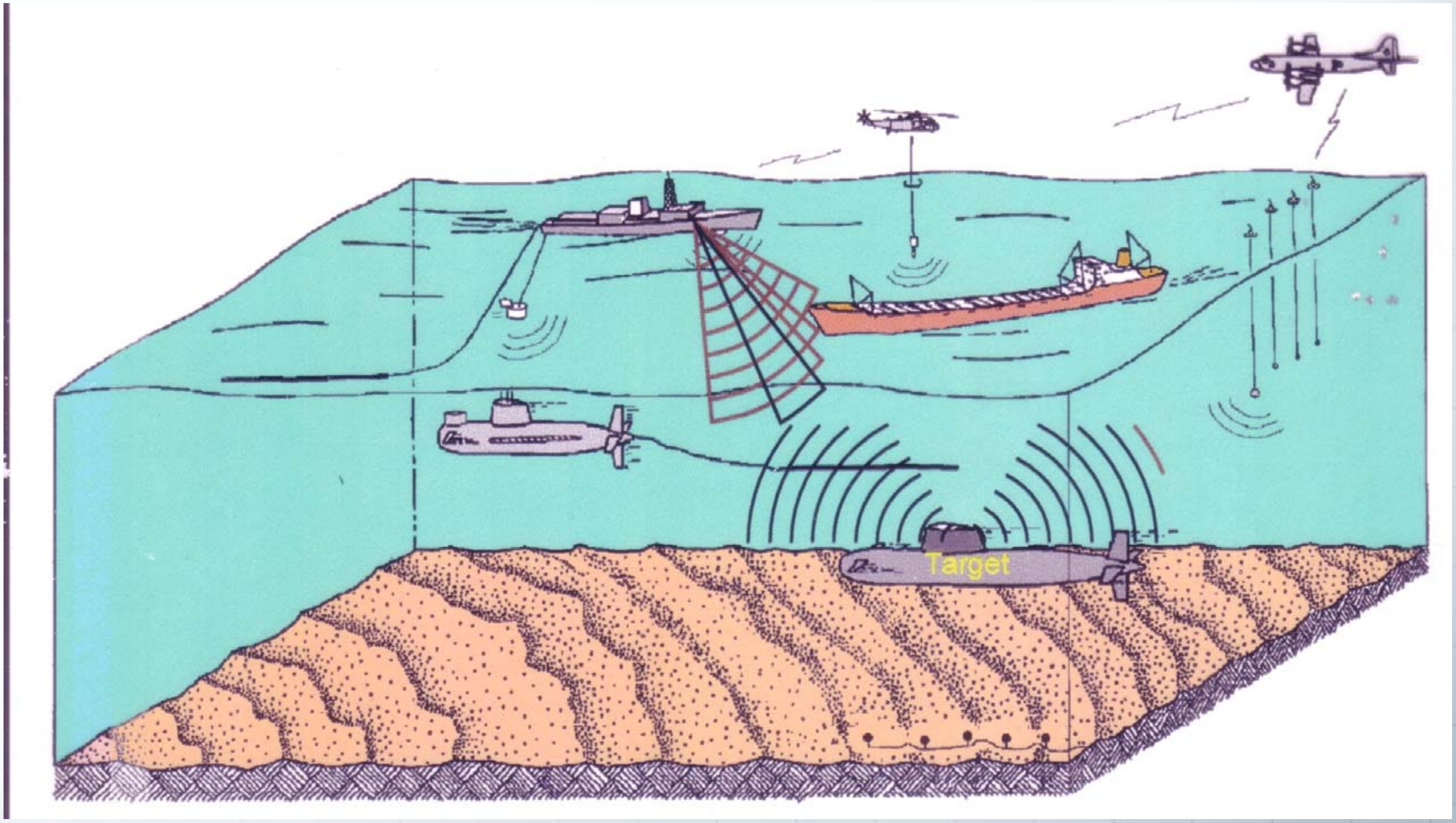
Past experience was focused on Active & Passive Sonar Operations for a wide variety of Naval Platforms with different type of sensors deployed in an underwater environment



Advanced 3D Beamformers for Multi-Sensor Sonar Systems

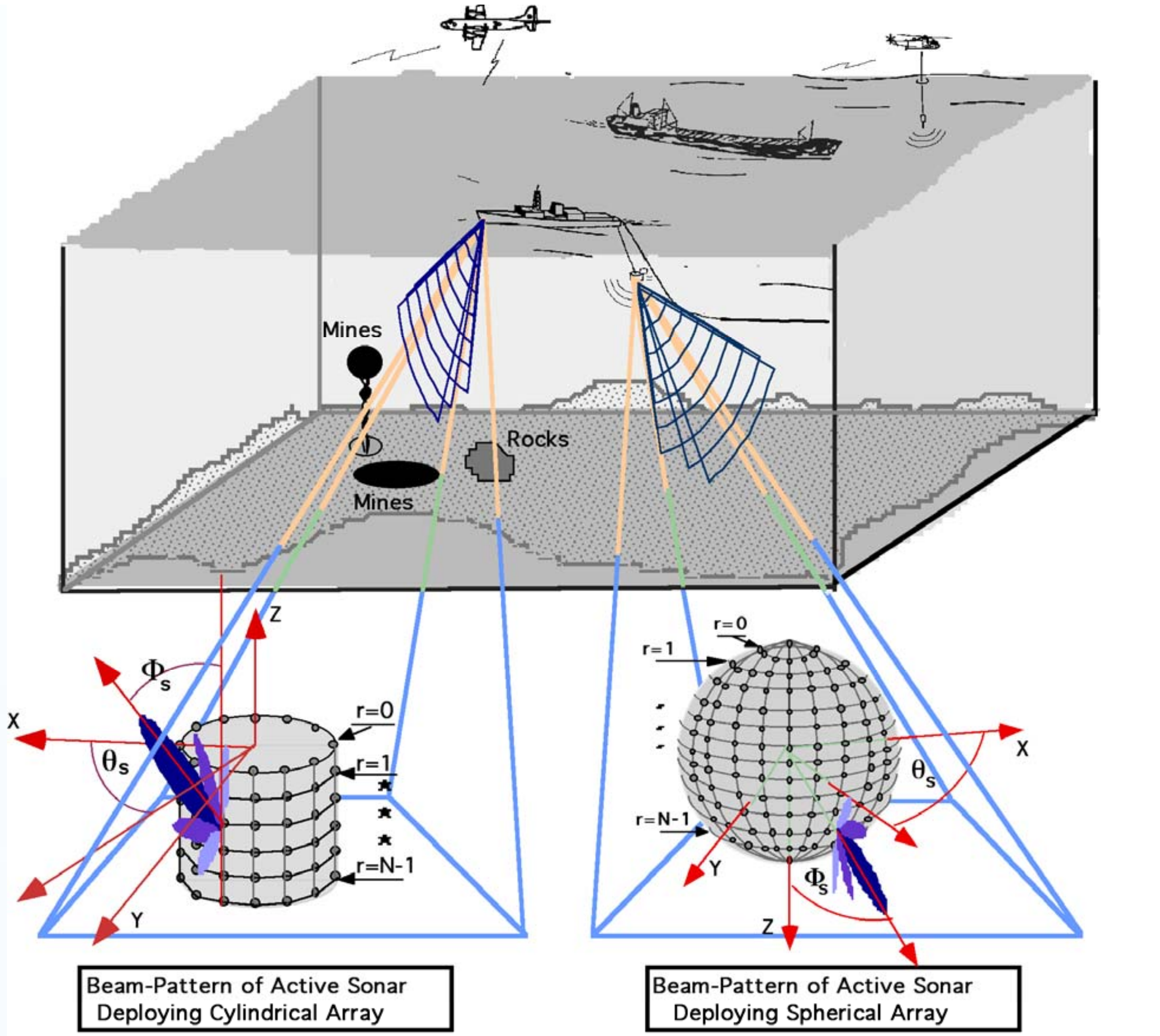
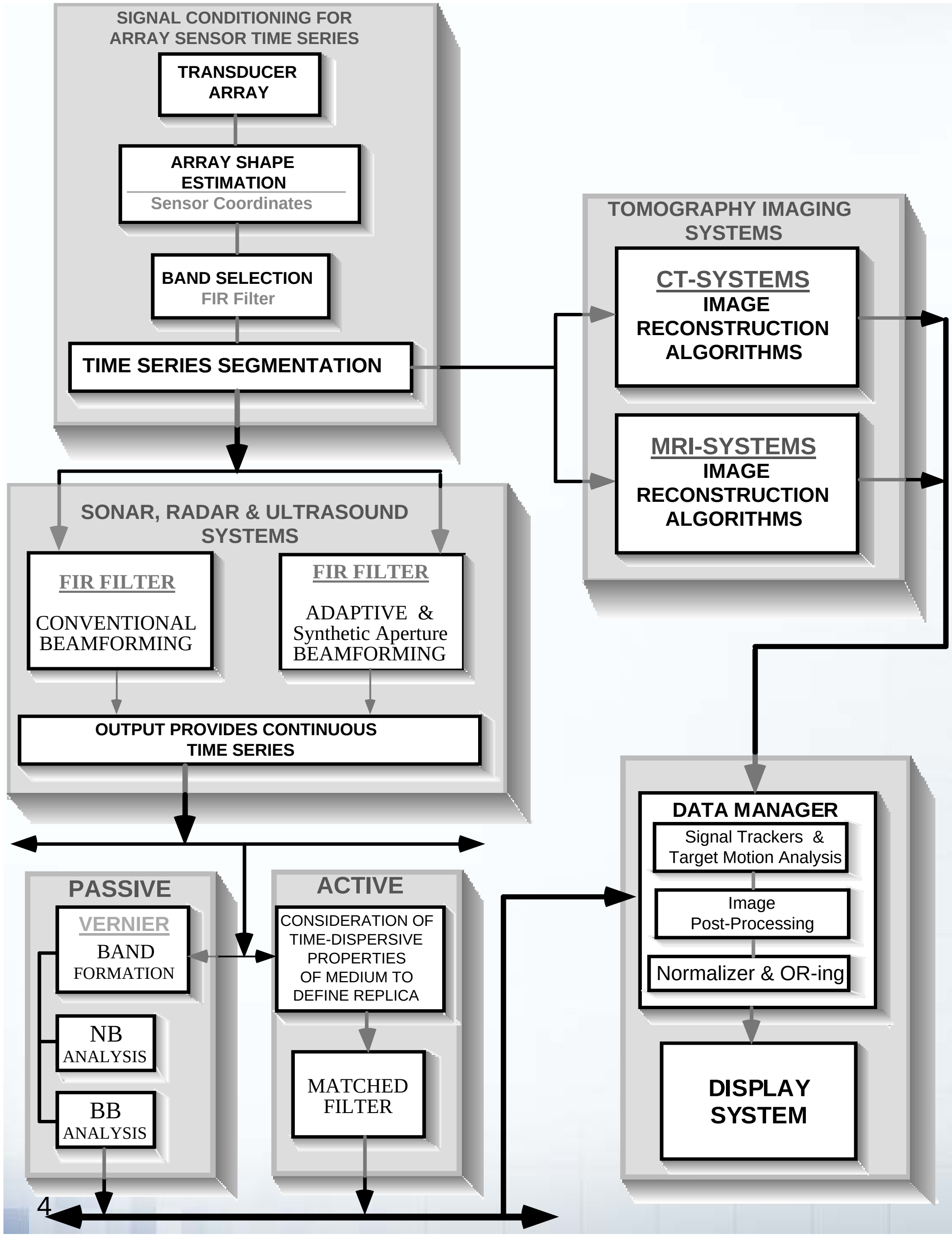


Figure 1

Generic Signal Processing Structure

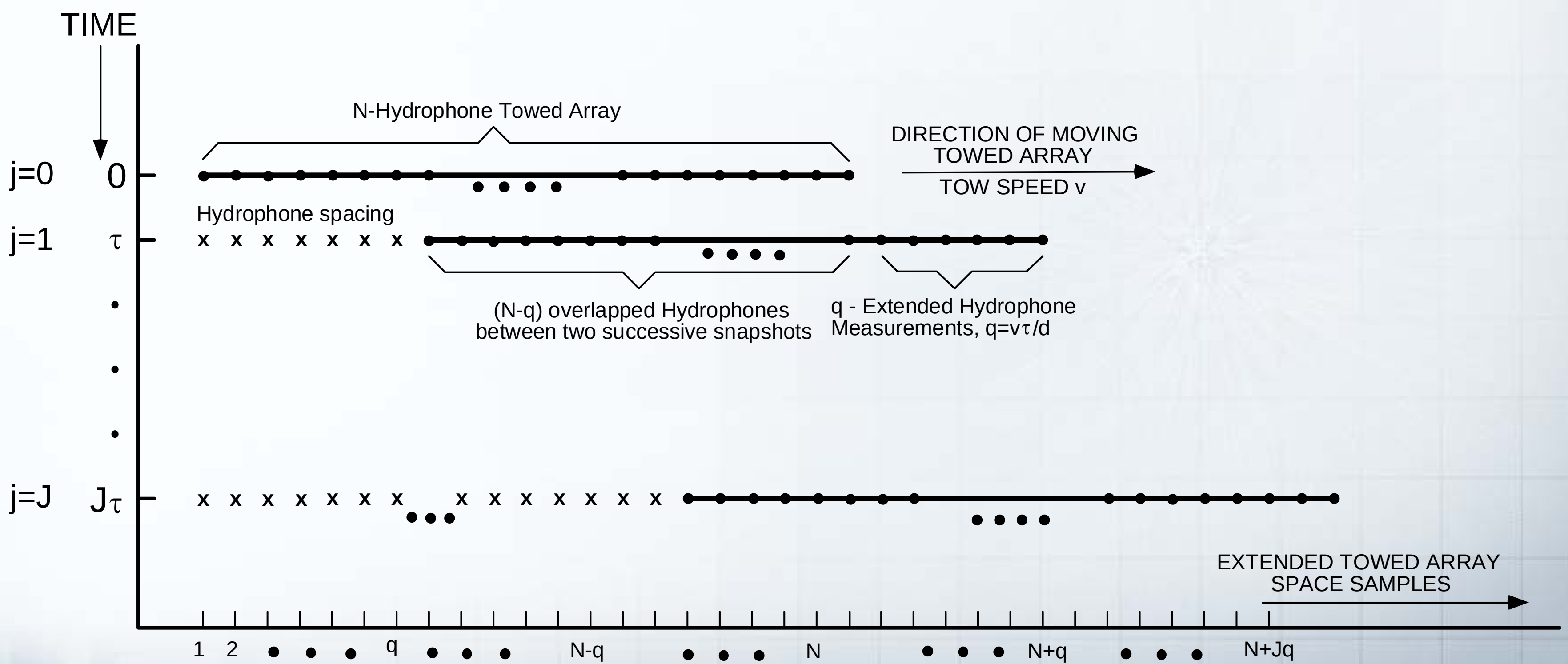


Synthetic Aperture for Sonar and Radar Systems

$$x_n(t_i+\tau)=\exp(j2\pi f_o\tau)A\exp\left[j2\pi f_o\left(t_i-\frac{\upsilon t_i+(q+n-1)\delta}{c}\sin\theta\right)\right]+\varepsilon_{n,i}^{\tau}$$

Overlap Correlator $\upsilon\tau = qd$

$$\tilde{X}_n(f)_\tau = \exp(j2\pi f_o\tau)\tilde{X}_n(f)$$



Synthetic Aperture for Sonar and Radar Systems

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OUTPUT OF VERNIER:

PROVIDES DOWNSAMPLED CONTINUES TIME SERIES FOR ALL N-HYDROPHONES OF AN APERTURE

SEGMENTATION AND OVERLAP OF CONTINUOUS TIME SERIES FOR ETAM ALGORITHM

WHERE: INDEXes (m,j) REFER TO
j=1,2,..,5 THE NUMBER OF 5 DISCONTINUOUS SEGMENTS REQUIRED BY THE ETAM ALGORITHM TO SYNTHESIZE AN EXTENDED APERTURE
m=1,2,... IS THE INDEX REFERING TO EACH OUTPUT OF THE ETAM ALGORITHM
n=1,2,...,N IS THE HYDROPHONE INDEX
i=1,2,....,M IS THE INDEX FOR THE TIME SAMPLES, THE PERCENTAGE OF OVERLAP BETWEEN SUCCESSIVE SEGMENTDS IS 12.5%

FOR EACH INDEX m

m=1 m=2 • • •

ETAM: OVERLAP CORRELATOR

FOR EACH DATA SET HAVING 5 DISCONTINUOUS SEGMENTS ESTIMATE

2K-POINT FFT OF $y_{(m,j),n}(t_i)$ INTO $Y_{(m,j),n}(f_i)$

i=0,1,...,M, j=1,2,..,5, & n=1,2,...,N

ESTIMATE THE CROSS-CORRELATION COEFFICIENTS:

$$\zeta_{(m,j)n}(f_o) = \frac{\sum_{i=a}^{b} \left\{ Y_{(m,j),N/2+n}(f_i) \times Y_{(m,j+1),n}(f_i) \right\}}{\left[\sum_{i=a}^{b} \left\{ Y_{(m,j),N/2+n}(f_i) \right\}^2 \times \sum_{i=a}^{b} \left\{ Y_{(m,j+1),n}(f_i) \right\}^2 \right]^{1/2}}$$

WHERE: [a,b] IS THE FREQUENCY RANGE OF INTEREST
f = (a+b)/2 IS THE CENTRE FREQUENCY

j=1,2,3,4 and n=1,2,...,N/2

ESTIMATE THE PHASE CORRECTION FACTOR:

$$\Psi_j(f_i) = \arg \left\{ \frac{\sum_{n=1}^{N/2} \left\{ Y_{(m,j),N/2+n}(f_i) \times Y_{(m,j+1),n}(f_i) \right\} \left\{ \zeta_{(m,j),n}(f_o) \right.}{\sum_{n=1}^{N/2} \zeta_{(m,j),n}(f_o)} \right\}$$

FOR j=1 EXTEND THE N HYDROPHONE APERTURE BY AN ADDITIONAL SET OF N/2 HYDROPHONE DATA SETS IN FREQUENCY DOMAIN

$$Y_{m,N+n}(f_i) = Y_{(m,j+1),N/2+n}(f_i) \times \Psi_j(f_i)$$

WHERE:
n=1,2,...,N/2 and i=1,...,M

FORM 2K-POINT IFFT OF $Y_{m,N+n}(f_i)$
n=1,2,...,N/2 and i=1,...,M
IN ORDER TO GET: $y_{m,N+n}(t_i)$
CONTINUOUS HYDROPHONE TIME SERIES FOR n=1,2,...,N/2 and i=1,2,...,M

FOR j=2,3,4 SYNTHESIZE EACH TIME N/2 ADDITIONAL HYDROPHONE TIME SERIES

$y_{m,3N/2+n}(t_i)$; $y_{m,2N+n}(t_i)$; $y_{m,5N/2+n}(t_i)$

WHERE n=1,2,...,N/2 and i=1,2,...,M

m=1 m=2 • • •

OUTPUT OF ETAM

$y_{m\,n}(t_i)$ FOR m=1,2,... n=1,2,...3N

OUTPUT OF ETAM PROVIDES 3N CONTINUOUS HYDROPHONE TIME SERIES AT THE INPUT OF A CONVENTIONAL BEAMFORMER

Adaptive Sup-Aperture Structure for Line Arrays

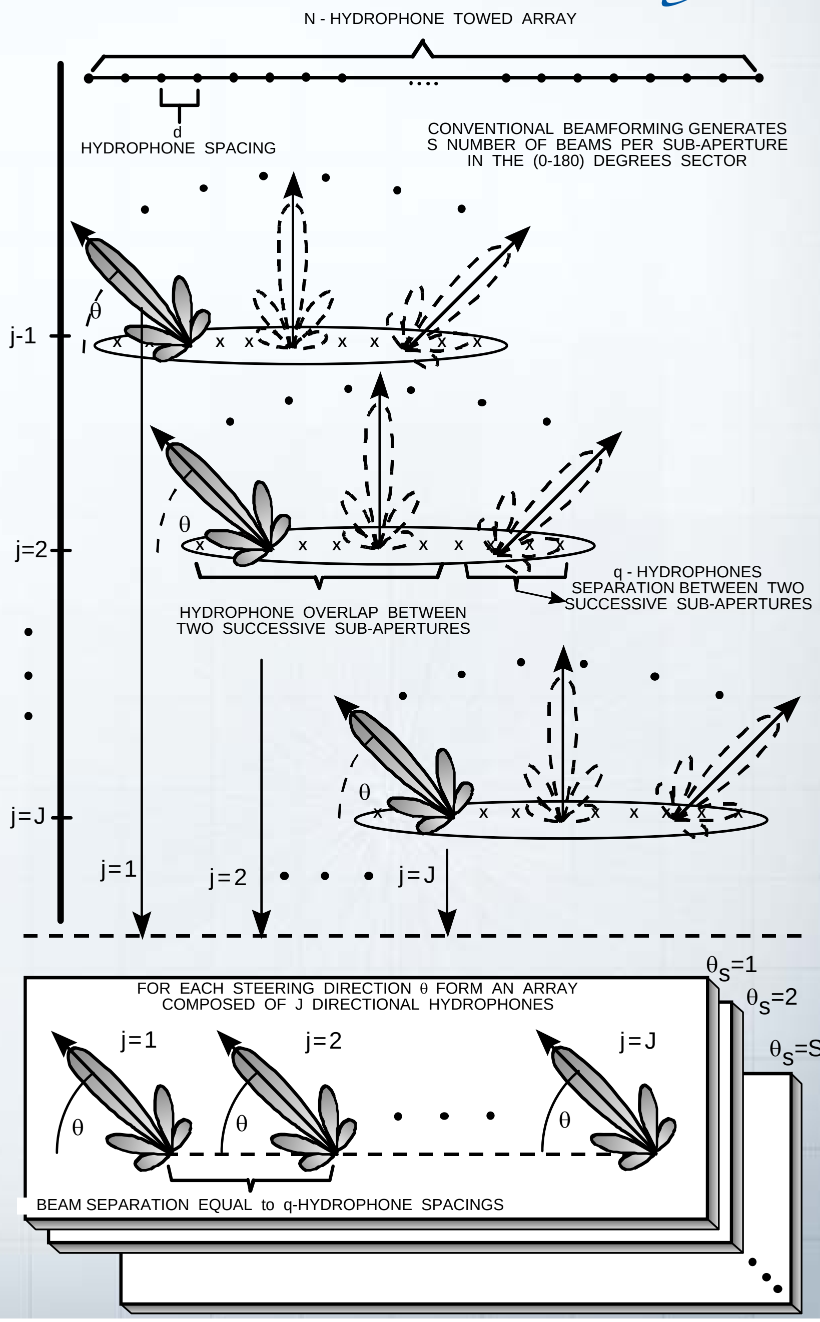
The line array is divided into a number of sub-arrays that overlap.

The sub-arrays are beamformed using the conventional approach; and <u>this is the first stage of beamforming</u>.

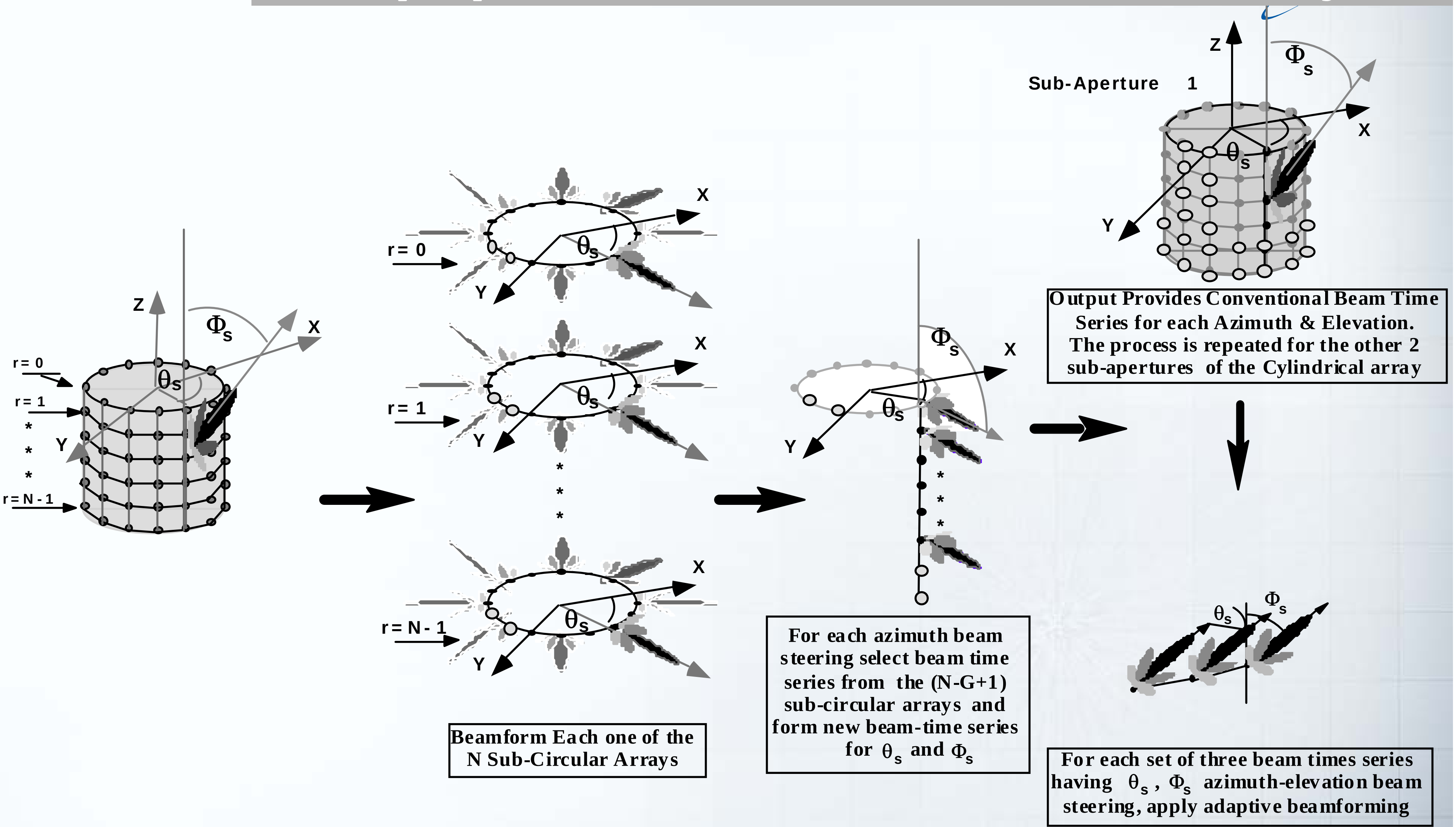
Then, we form a number of sets of beams with each set consisting of beams that are steered at the same direction but each one of them generated by a different sub-array.

A set of beams of this kind is equivalent to a line array that consists of directional sensors steered at the same direction, with sensor spacing equal to the space separation between two contiguous sub-arrays and with the number of sensors equal to the number of sub-arrays.

<u>The second stage of beamforming</u> implements an adaptive scheme on the above kind of set of beams, as illustrated in Figure.

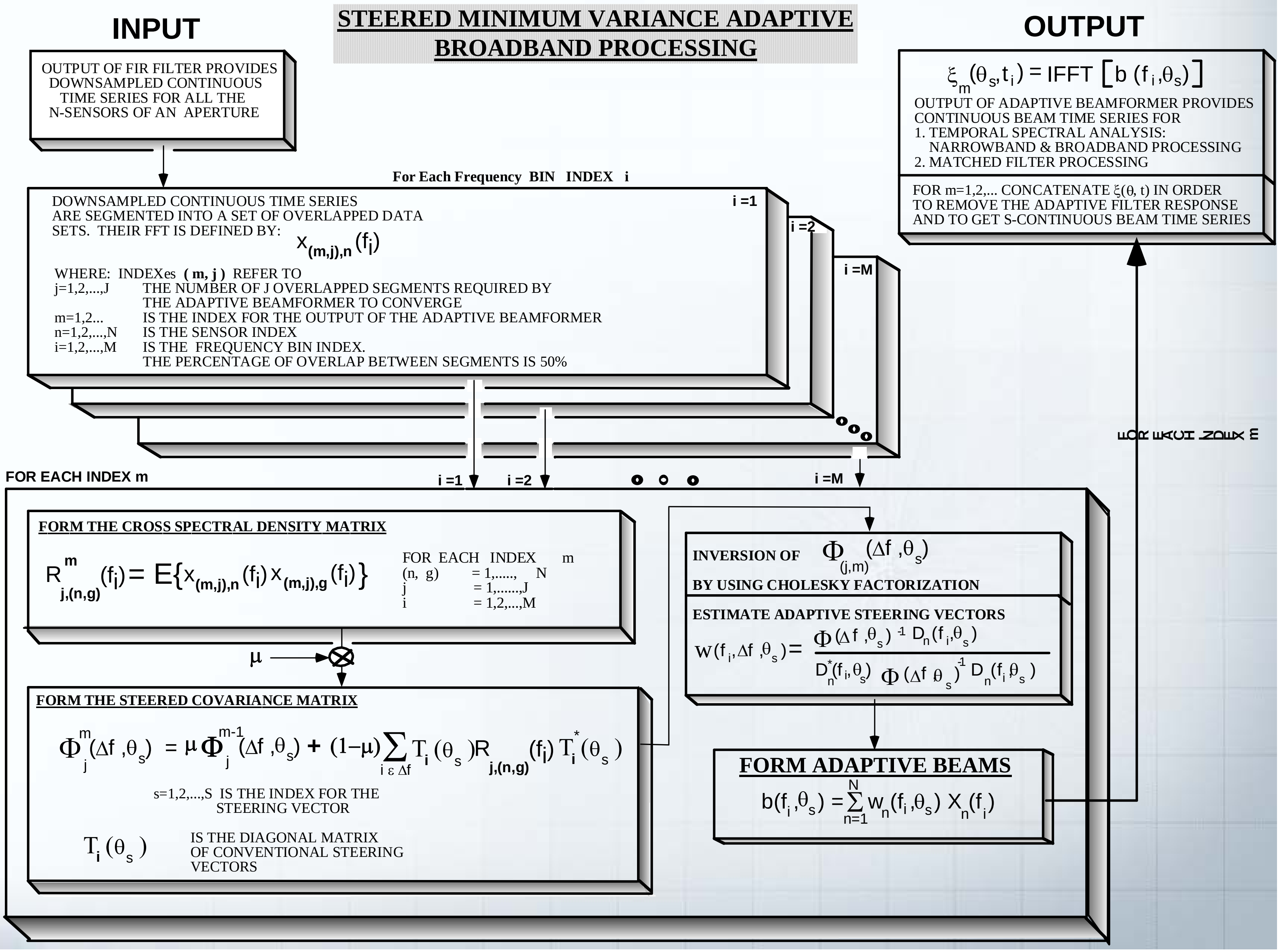


Sup-Aperture Structure for CiLindrical Arrays

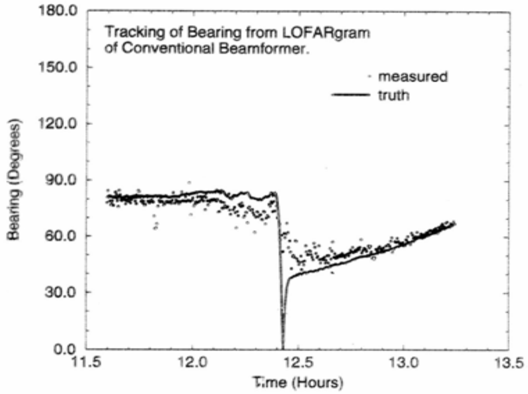


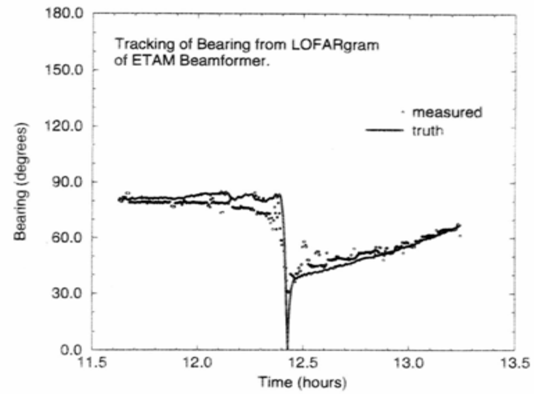
Stergiopoulos S. and Geoffrey Edelson, *“Theory and Implementation of Advanced Signal processing for Active and Passive Sonar Systems”, Handbook on Advanced Signal Processing for Sonar, Radar and Medical Imaging Systems, Editor: S. Stergiopoulos, CRC Press LLC, Boca Raton, FL, USA, March 2000.*

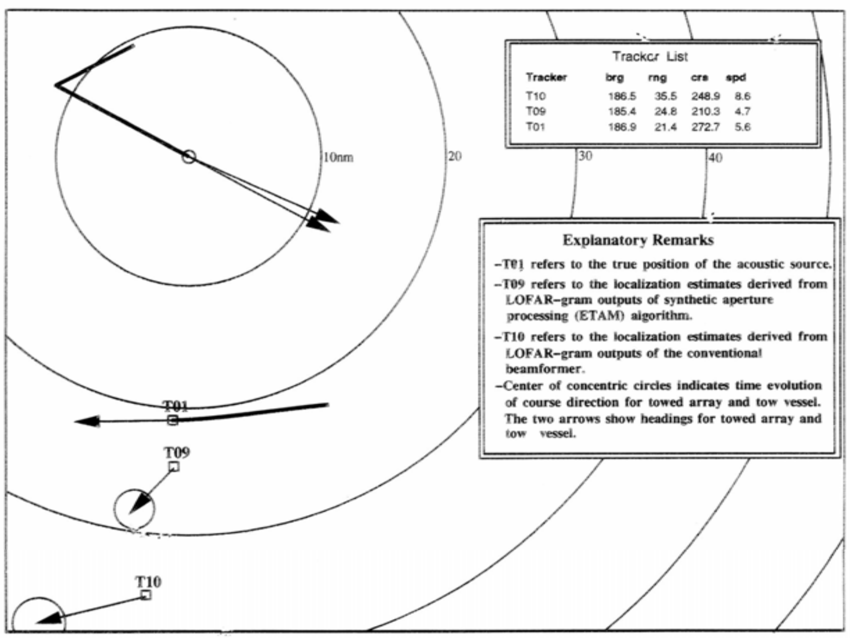
Adaptive Processing for Sonar Systems

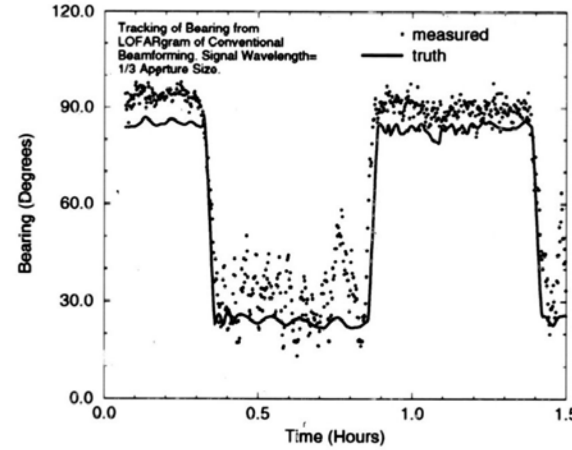


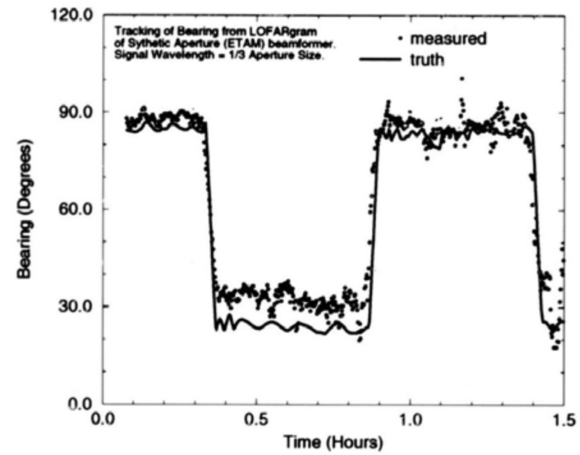
Stergiopoulos S., "*Implementation of Adaptive and Synthetic Aperture Beamformers in Sonar Systems*", The Proceedings of the IEEE , 86(2), 358-396, Feb. 1998.

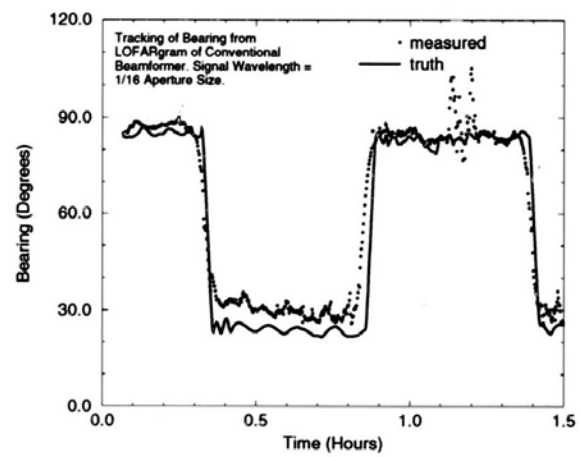




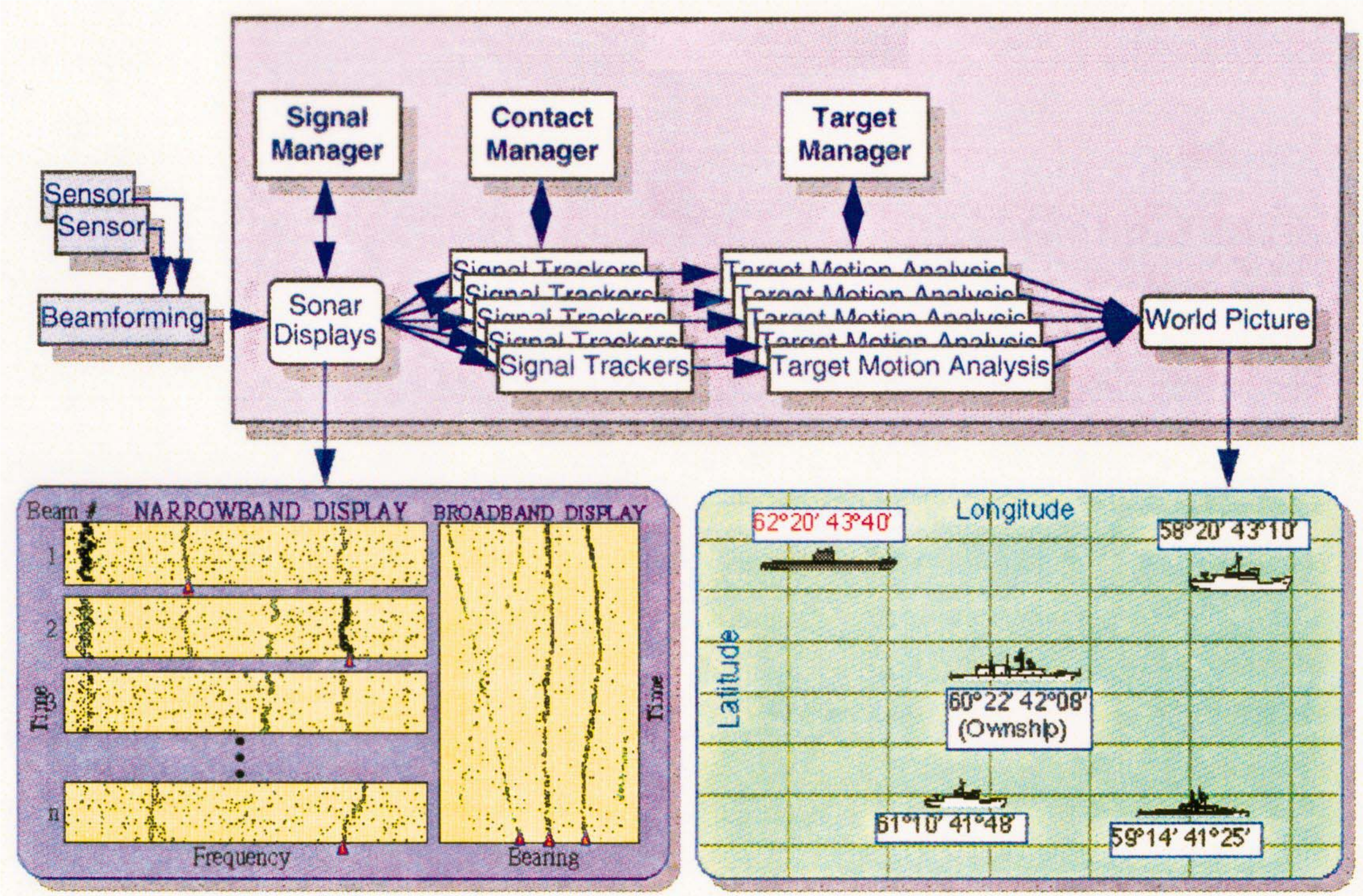








Tactical Picture
Post-Processing (FUSION) for Sonar and Radar



R&D Efforts are the results of European-Canadian Collaborative Projects on x-Ray CT, MRI & 3D Ultrasound

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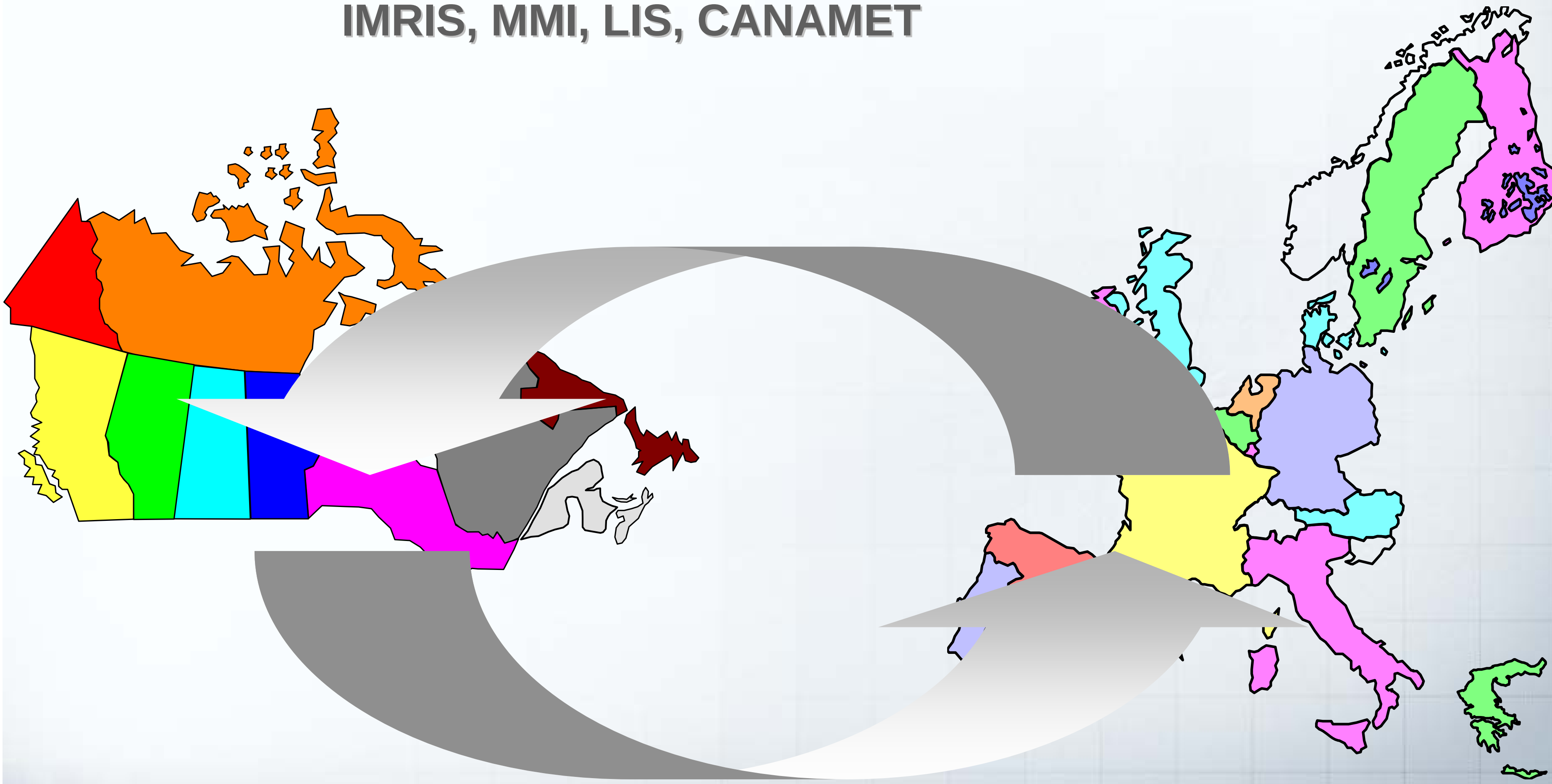
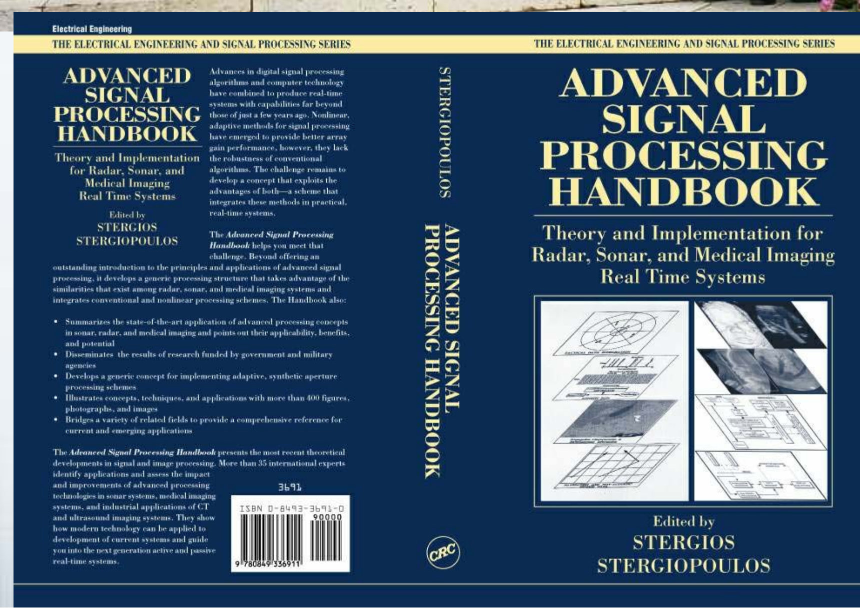
Europeans: Siemens, Philips, Nucletron, Bruel Kaer, Esaote, Fraunhofer

Canadians: UWO, RRI, LRI, UoT, DND/DCIEM IMRIS, MMI, LIS, CANAMET



FOURIER Euro-Workshop Supported by EC-IST

❖ **Objective:** Technical exchange among world-wide leading experts on advanced signal processing. The end result of the Fourier EuroWorkshop was the preparation of a Handbook on Advanced Signal Processing, Theory & Implementation for Sonar Radar and Medical Imaging Systems. Publisher is CRC-Press with Editor Dr. Stergiopoulos.



EC-IST Funding

EC-Esprit #26764-New Roentgen Project: Cardiac X-ray CT,
Total funding: Euro 1.5 million, 1998-2000, Partners: Fraunhofer, Siemens, SEMA Group, DRDC

EC-IST-1999-10618 MITTUG, Project: Ultrasound Technology for Brachytherapy applications
Total funding: Euro 2.2 million, 2000-2003, Partners: Fraunhofer, Nucletron, DRDC-Toronto, University of Western Ontario(LHRI)

EC-IST-2000-28168 MRI-MARCB, Project: Cardiac Motion Correction for MRI imaging diagnostic
Total funding: Euro 1.5 million, 2001-2004, Partners: Fraunhofer, Philips, DRDC-Toronto, University of Western Ontario(LHRI)

EC-IST-2001-34088 ADUMS, Project: Fully Digital portable 3D Ultrasound Technology
Total funding: Euro 2.0 million, 2002-2005, Partners: Fraunhofer, ESAOTE, ATMEL, CANAMET, University of Toronto

EC-IST-2002, DUST, Project: Identification of Dual-Use Military Technologies
Total funding: Euro 0.75 million, 2002-2003, Partners: Defence European Labs from Netherlands, UK, Denmark, Canada DRDC

Euro-Conference: FOURIER Project: Euro-Conference on Dual-Use Technologies
Total funding: Euro 100,000, April-2000, Corfu, Greece
Partners: World-Wide Experts from Defence and Industrial Labs from North America and EU States.

Intellectual Properties

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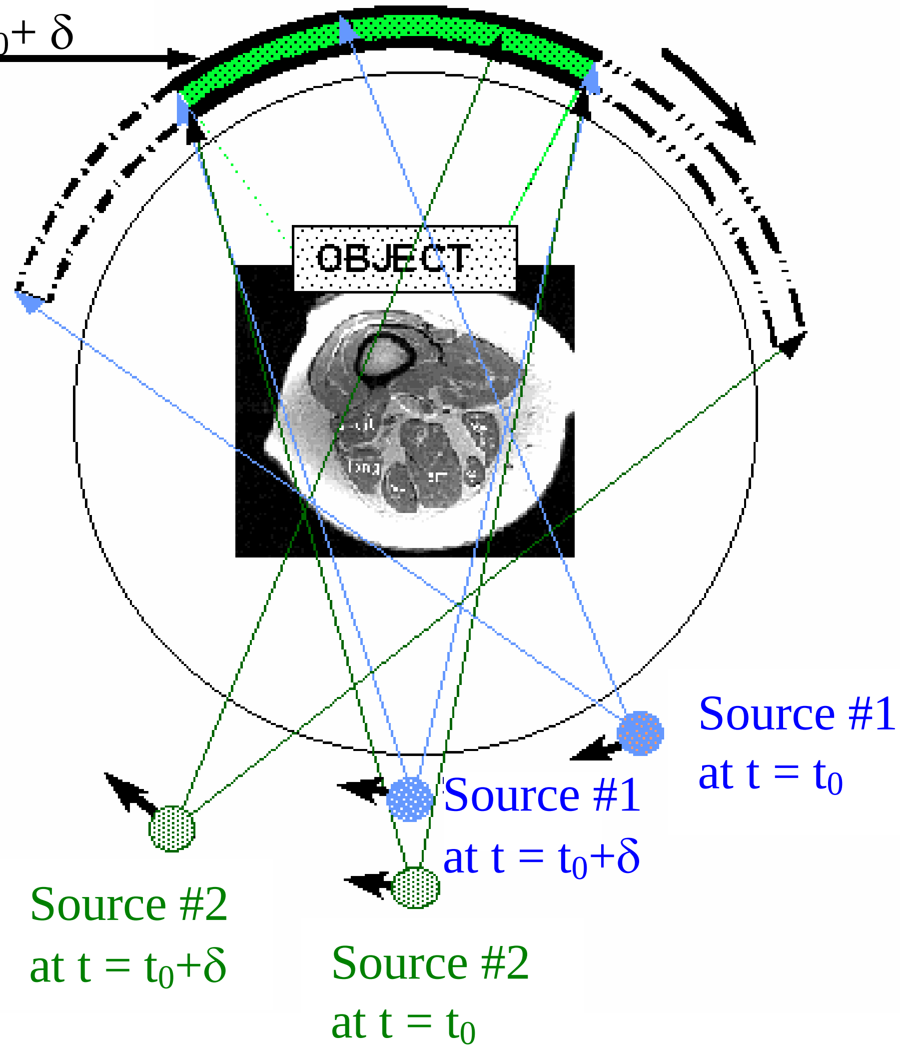
DRDC's Technologies are in the fields of

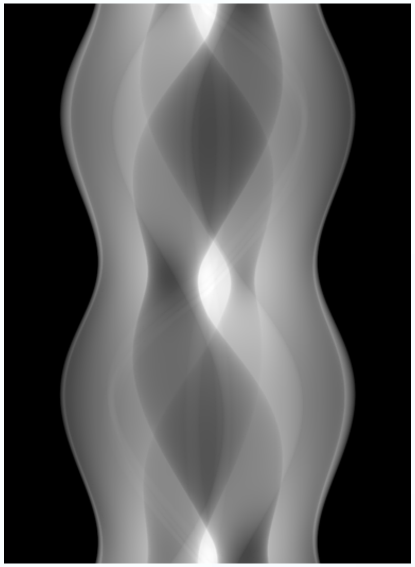
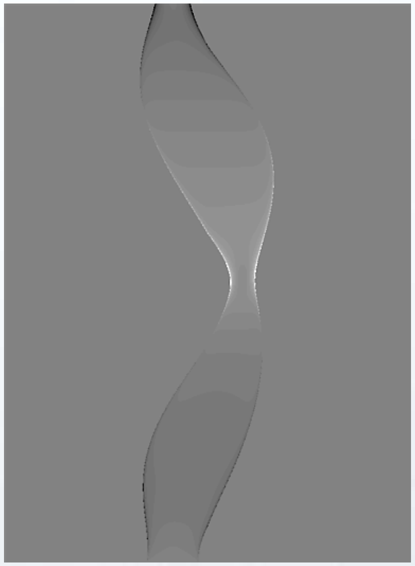
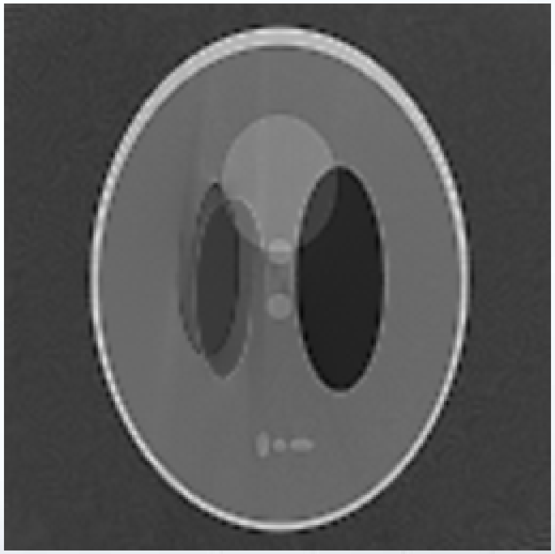
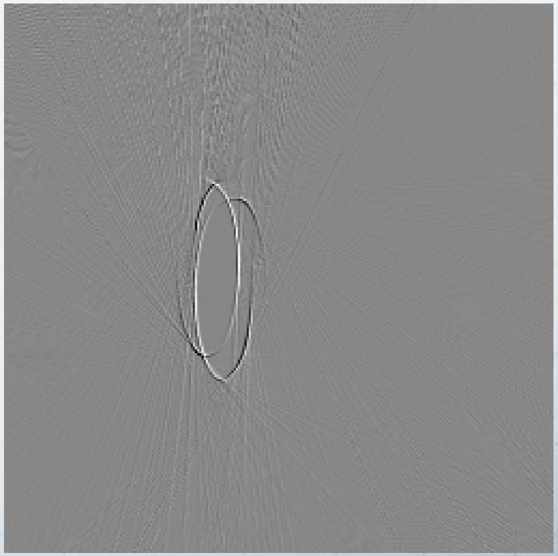
- Non-Invasive Medical Diagnostic 3D Imaging
  - Cardiac-3D CT motion correction
  - 3D/4D Ultrasound Imaging
  - Image Enhancement by Blind Deconvolution
- Monitoring Vital Signs
  - Automated Motion & Noise Tolerant Blood Pressure Systems
  - Vital Signs (ECG, Pulse Oxymetry, Thermometers, BP)
  - Intracranial Ultrasound for detecting Brain Injuries and Stroke
- Ultra Wide Band Wireless (Interference Free) Technology

The Spatial Overlap Correlator for x-ray CT

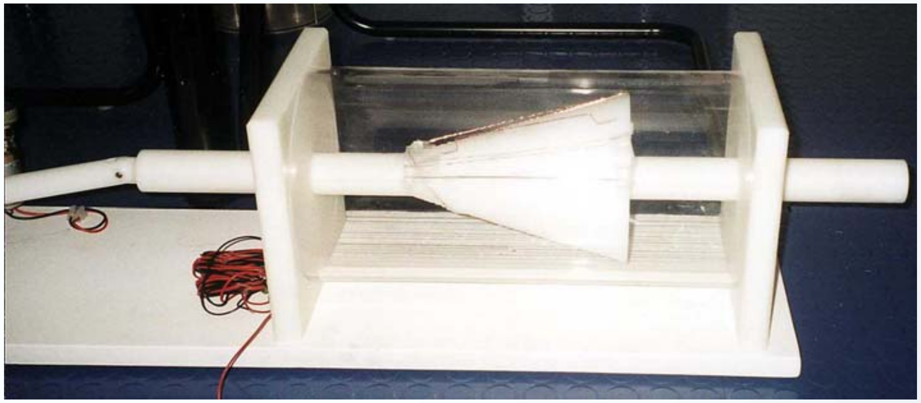
Spatially overlapping detectors sampling object with Source #2 at time $t = t_0$ and Source #1 at time $t = t_0 + \delta$



Outputs from SOC

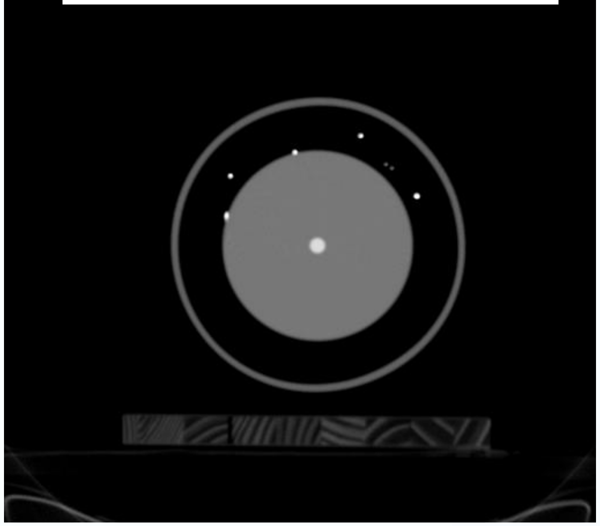
Original	SOC Measurement
	
	

Experiments with Moving Phantom

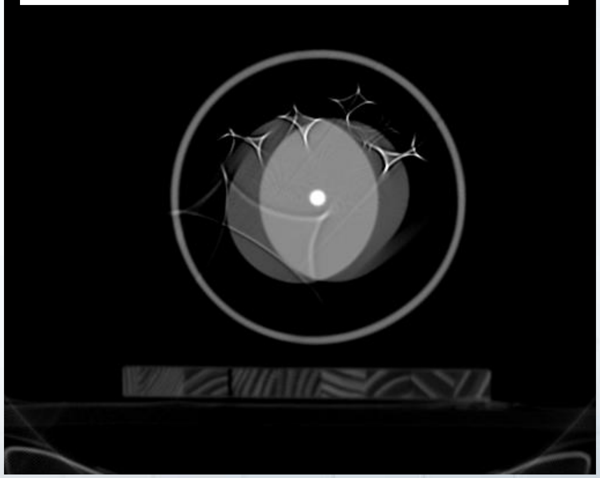


Experiments with Moving Phantom
Period of Motion = 0.6s

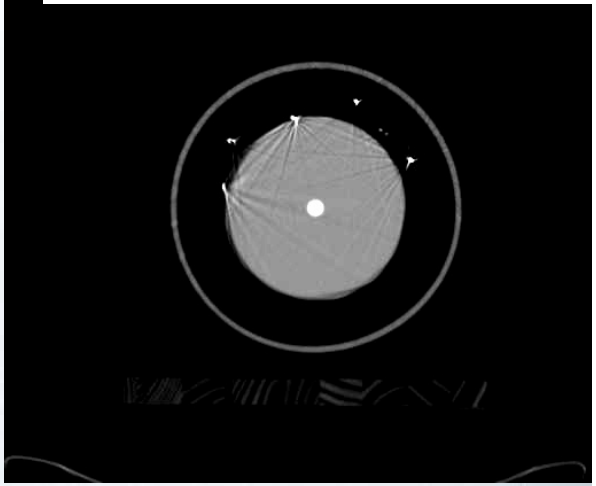
Stationary-Phantom



Moving-Phantom
Image Reconstruction using X-ray CT scanner



Moving-Phantom
Image Reconstruction using CANAMET's S/W



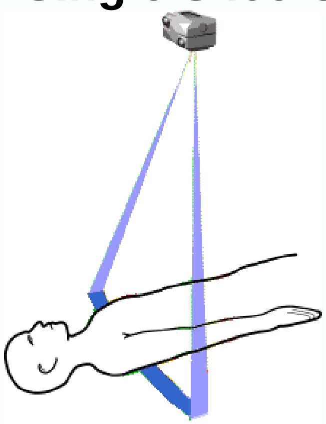
Clinical Trials
Cardiac Motion Correction Results

Motion artefacts present
(calcification not visible)

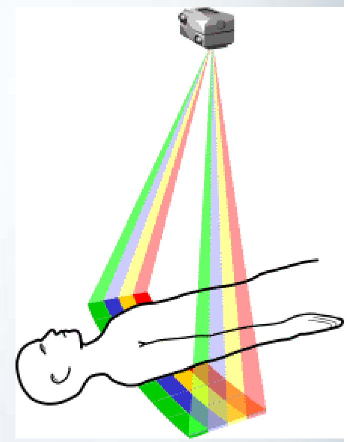
Motion artefacts removed
(calcification visible)

Applicable for Multi-Slice CT Scanners

Single Slice CT



Multi Slice CT

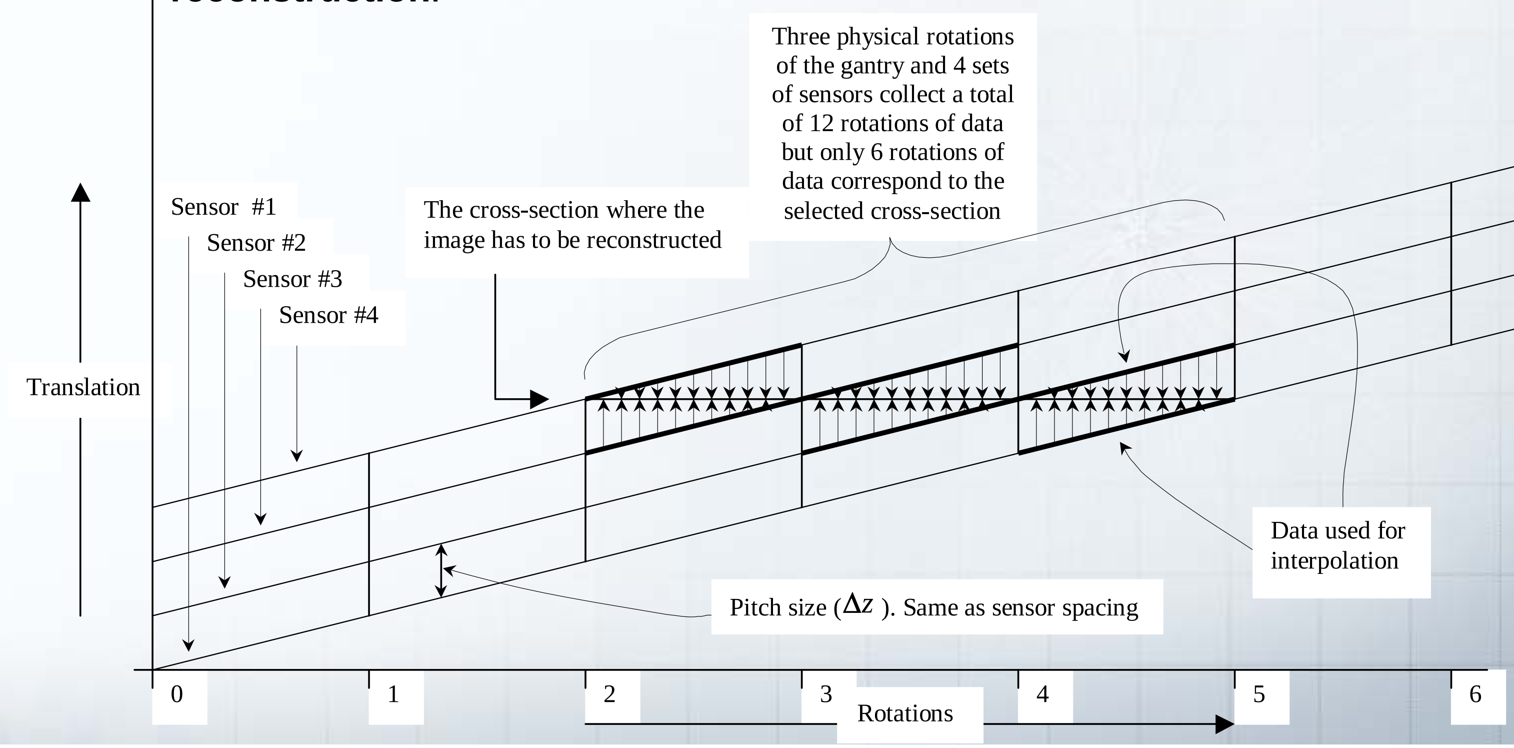


A total of six rotations of data (shown with thick lines) are used for the given cross-section. This data was spread from $-\Delta z$ to Δz around the cross-section

1.The 360-degree interpolation produced three rotation data for the selected cross-section.

2.This interpolated data is used by *motion phase identification algorithm* to detect the diastole phase of the cardiac cycle.

3.Finally, a 'clean' (180 +fan) data will be used for image reconstruction.



DRDC's Cardiac CT Technology

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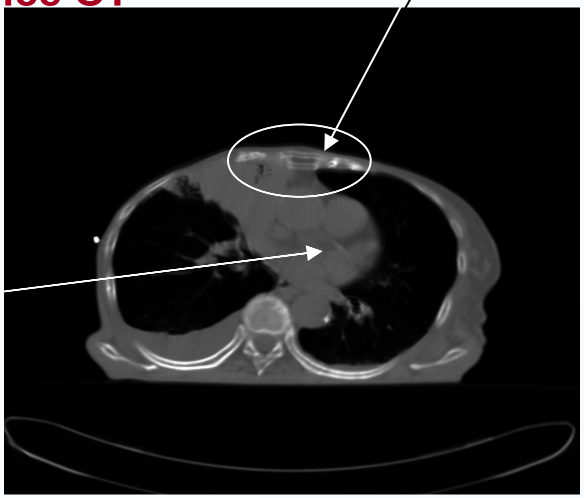
Image Output From Single Slice CT

Motion Artifacts

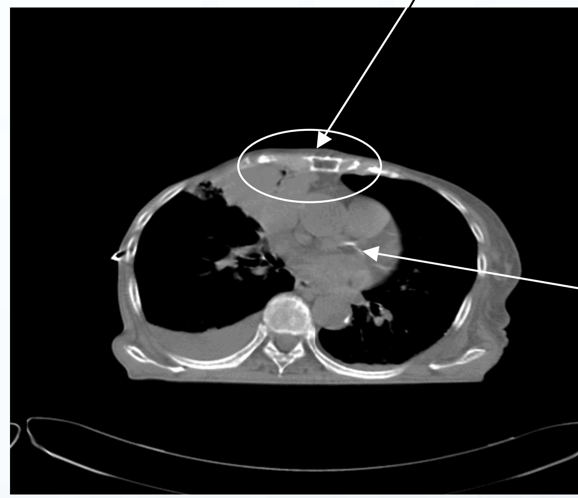
Blocked Heart Coronary Artery

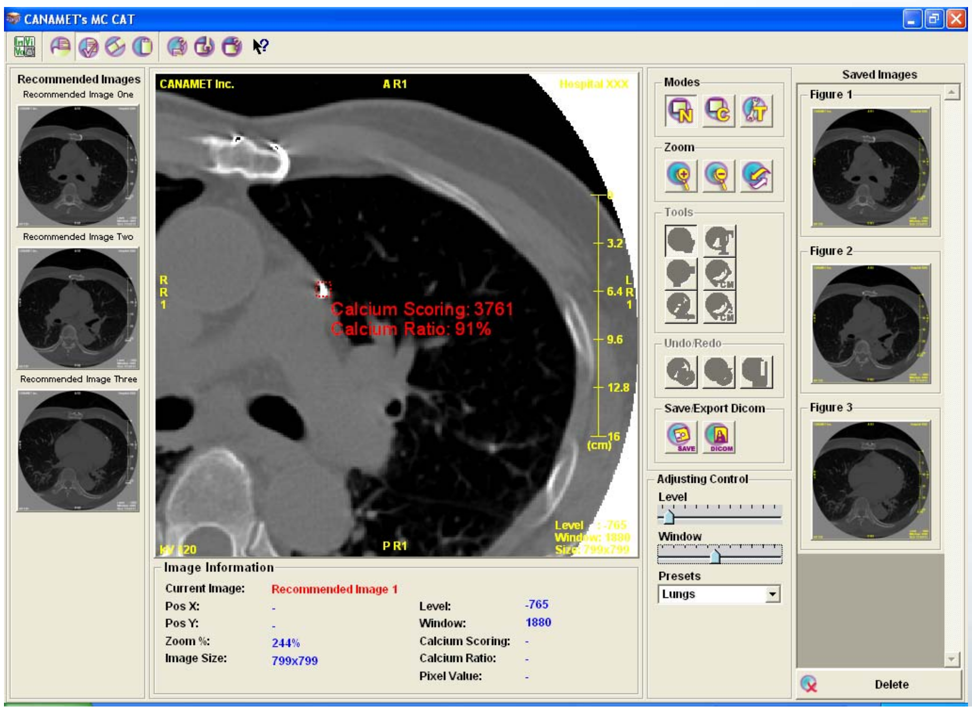


Motion Artifacts Removed

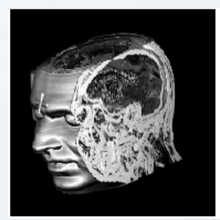
DRDC's CT Motion Correction Output

Blocked Heart Coronary Artery

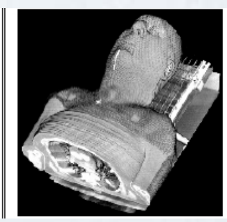




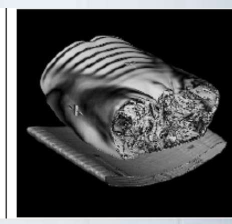
3D Visualization



3D Brain Imaging



3D Cardiac & Thorax Imaging



Abdominal For Prostate and Minimally Invasive Image Guided Surgery

Image Enhancement Using Blind Deconvolution

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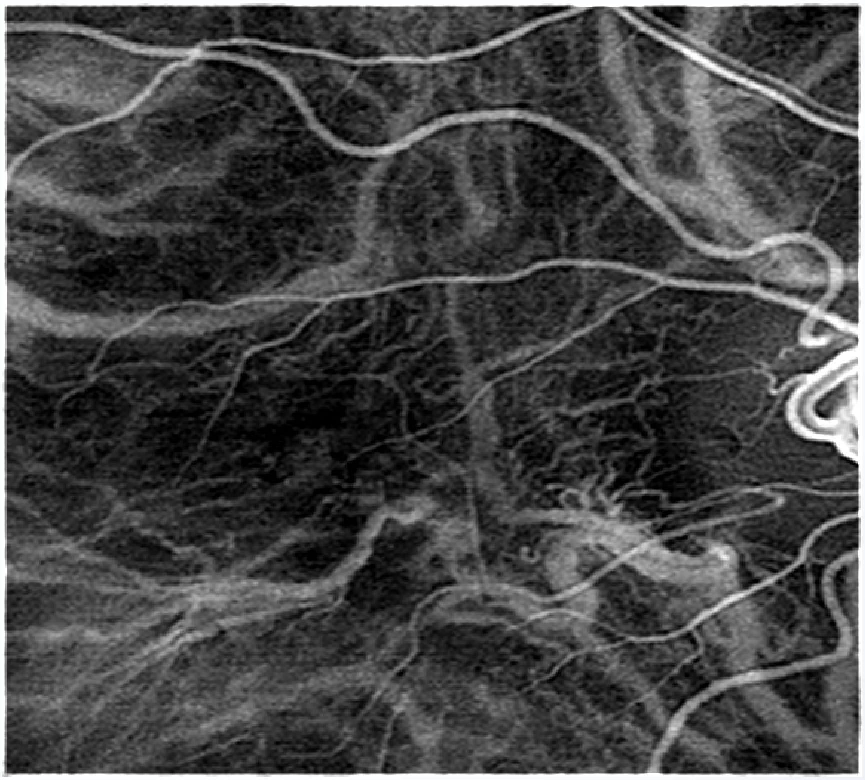
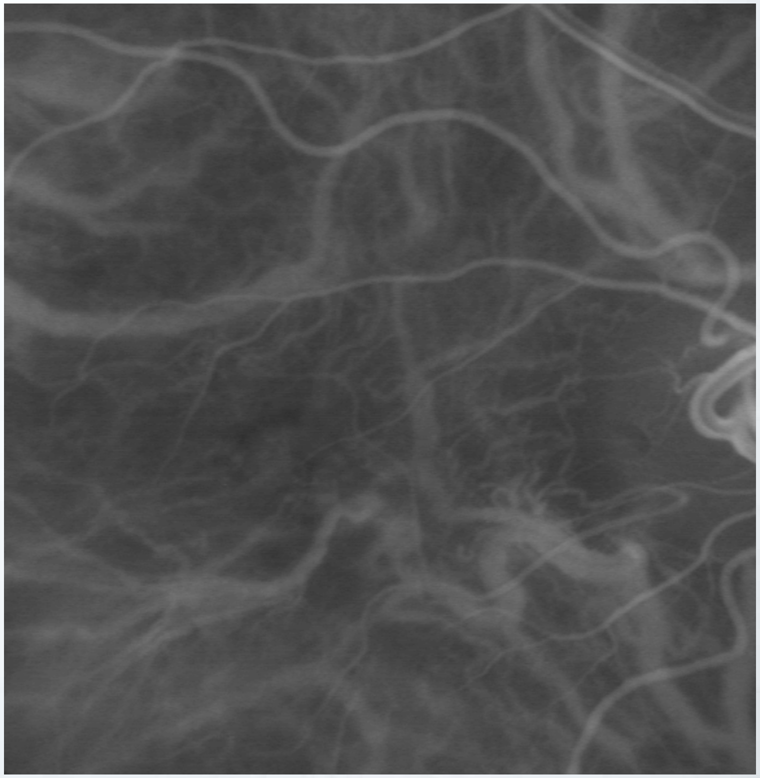


DRDC's Blind Deconvolution
Image processing Output for the Same Image



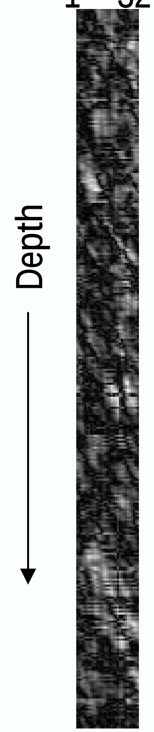
NOVADAQ's Original Image

Acoustic Tomography for Detecting Land Mines

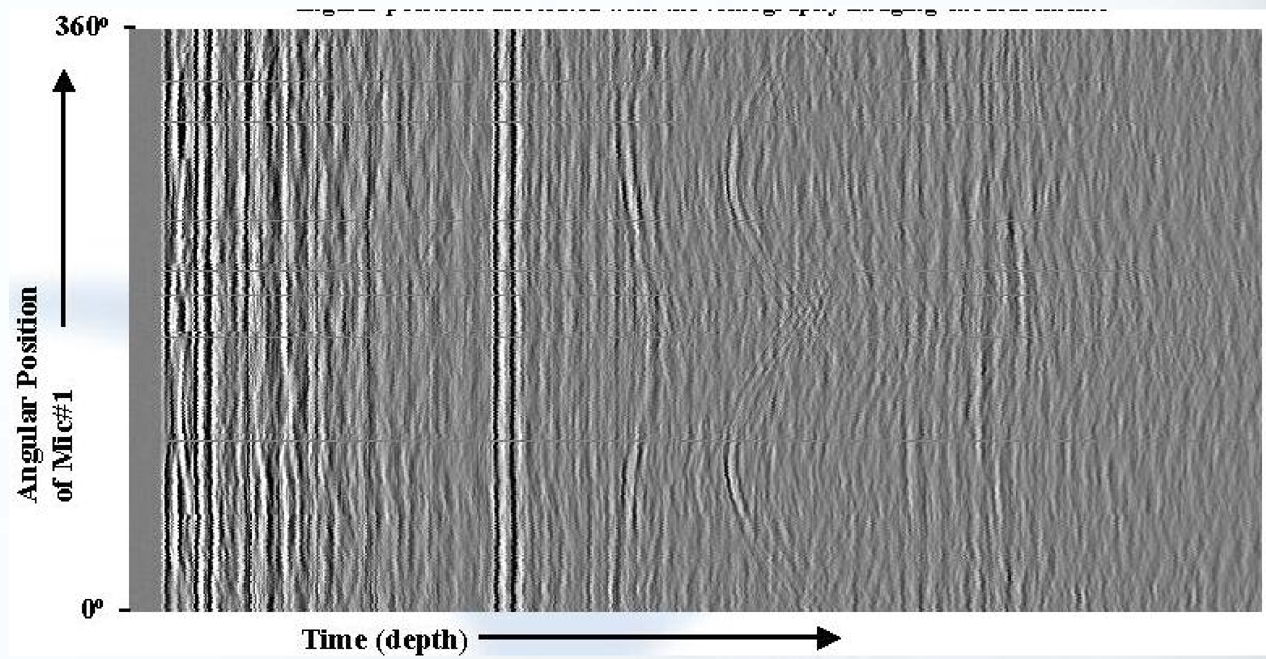
<u>Younis W., Stergiopoulos S., Havelock, D., Groski J</u>., "*Non-Distructive Imaging of Shallow Buried Objects Using Acoustic Computed Tomography* ", J. Acoust. Soc. Am., 111(5), 2117-2127, 2002.

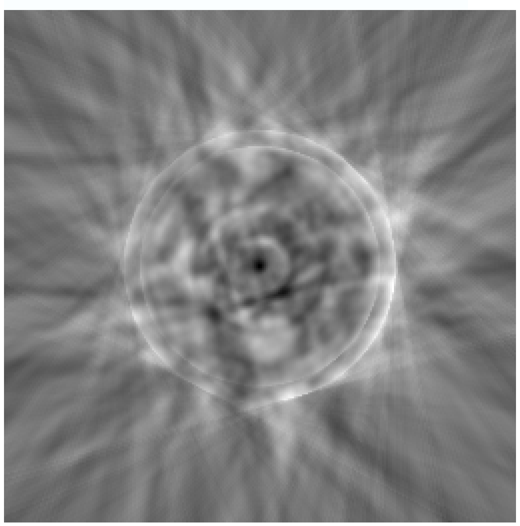
Acoustic Tomography for Detecting Land Mines

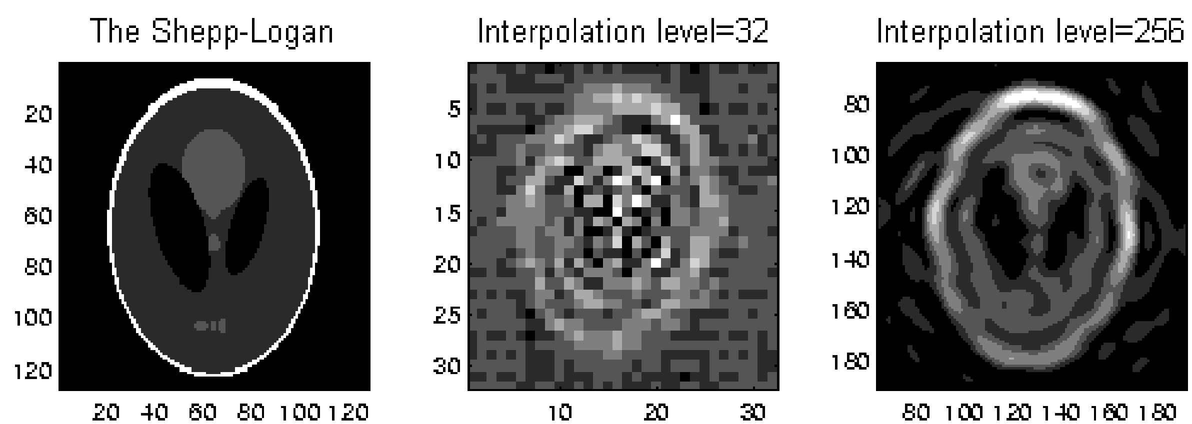
Sensors
1 - 32



Gram for a single acoustic-sensor around 360-degrees







3D Portable Ultrasound Technology

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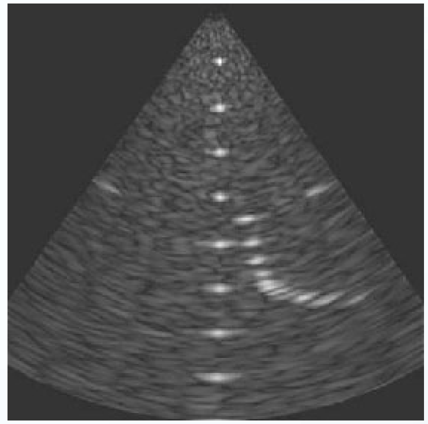
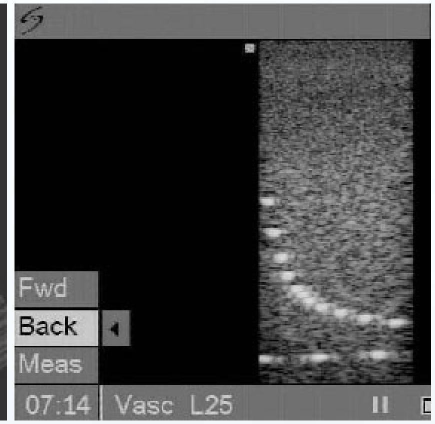
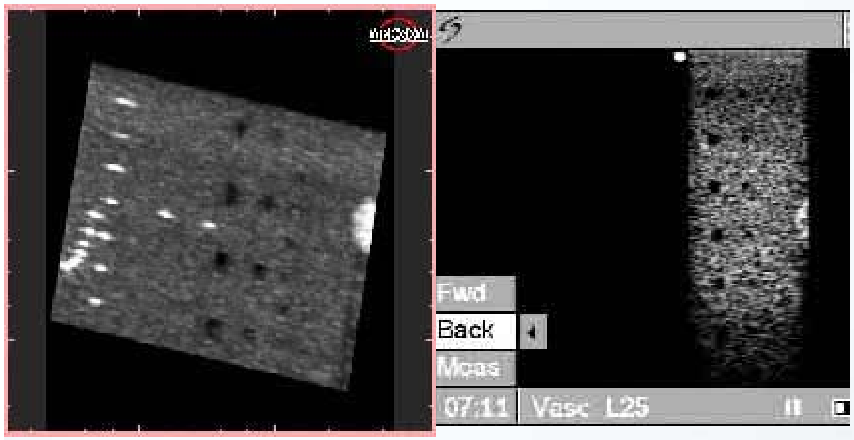
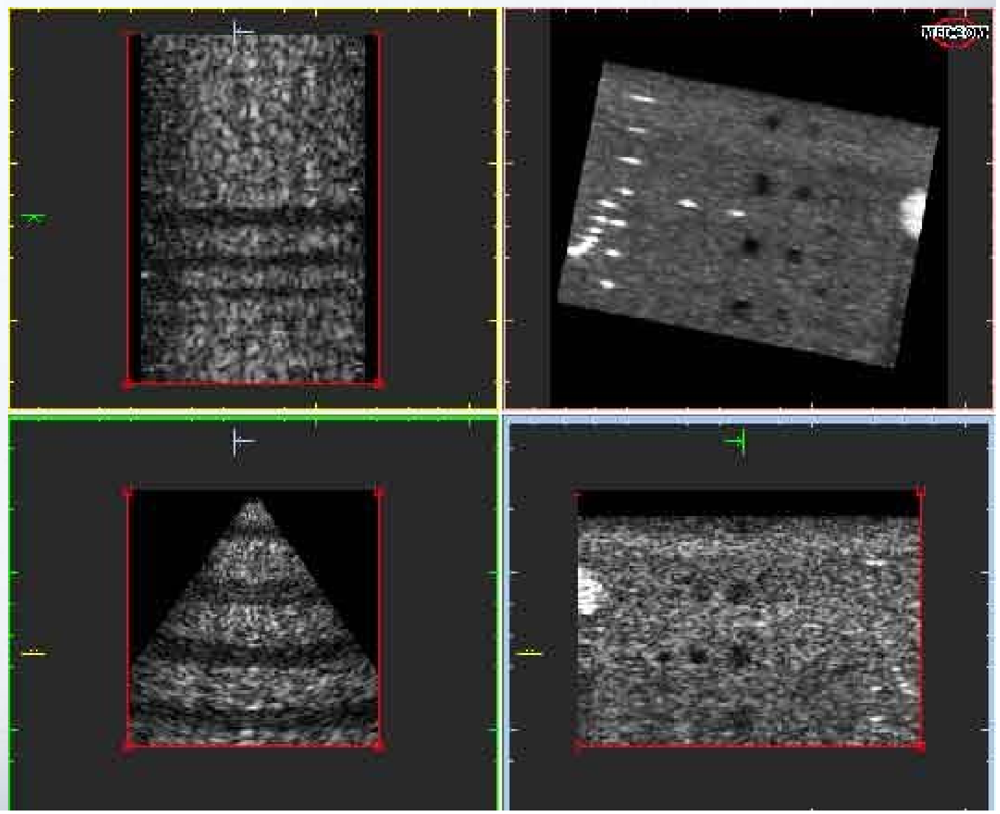
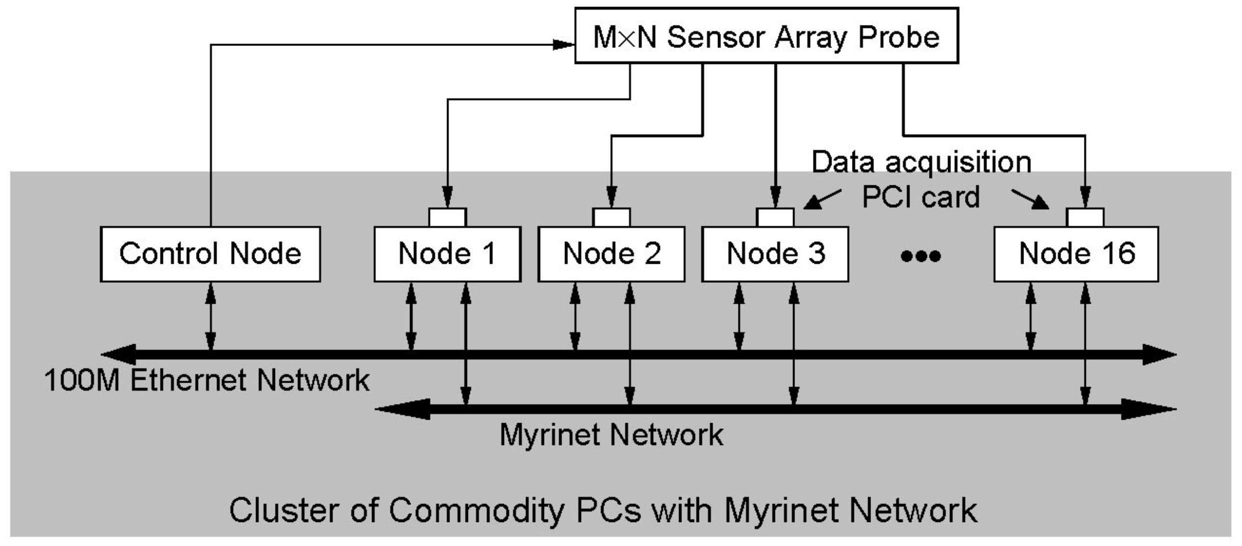








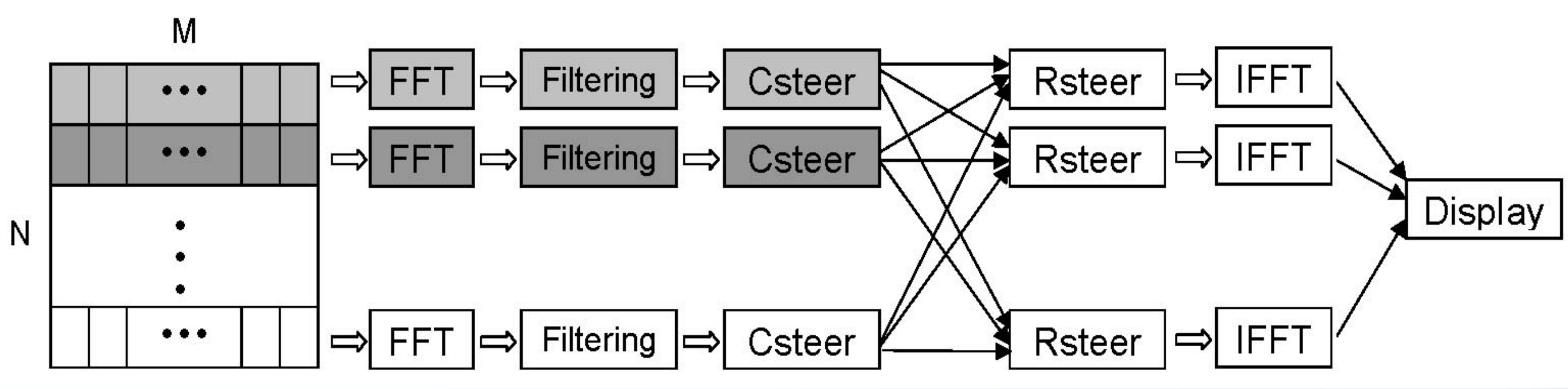
Scalable Multi-node PC Cluster



Architecture of PC Cluster Network

Cluster of Commodity PC's with high speed Myrinet network

Efficient Beamformer Implementation



- ❖ Decompose input data to each processor by each row of sensors
  - ➢ Maximize parallelization and minimize communication between processors
  - ➢ Can be decomposed by each element of the sensors, however increases data traffic among processors
- ❖ MPI is used as the communication abstraction

3D Animations

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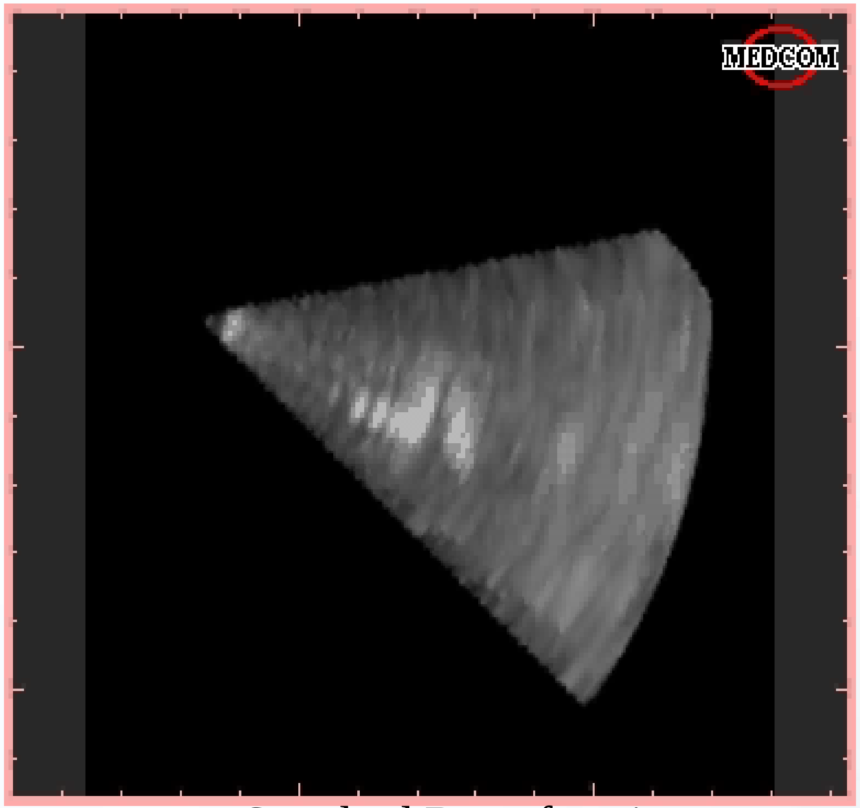
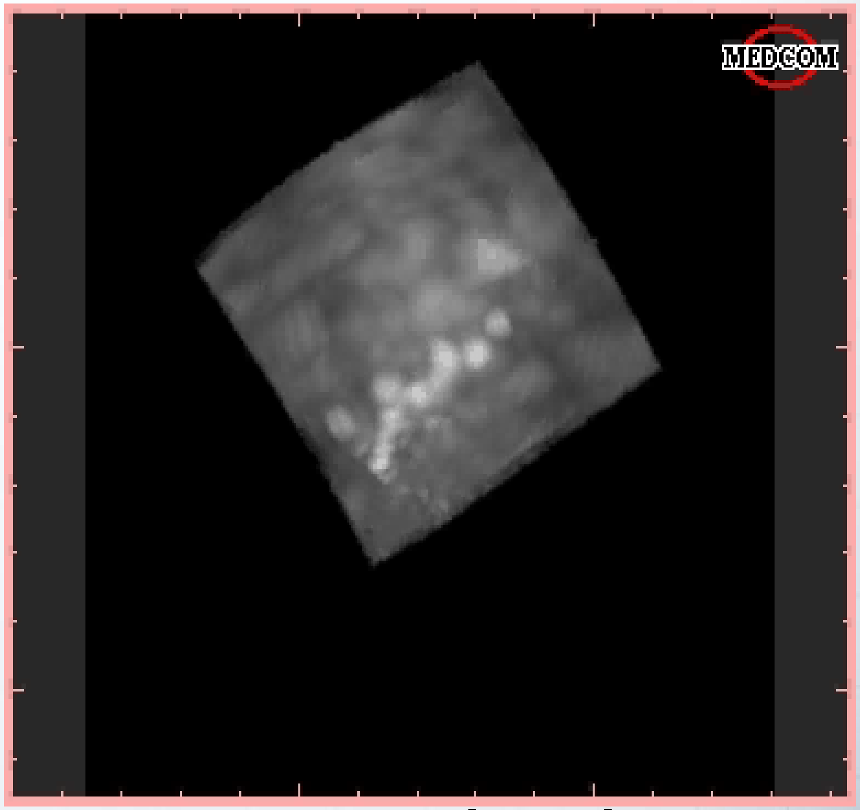


Standard Beamforming



Canamet's Advanced Beamforming

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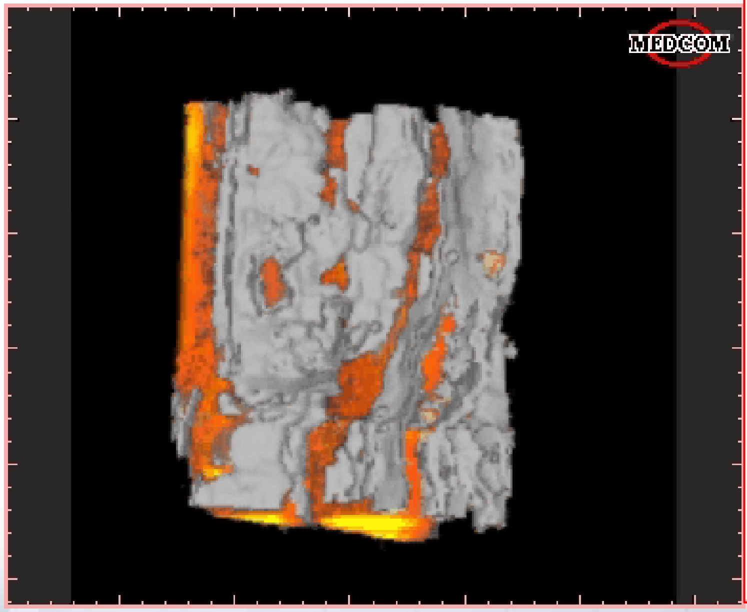
The proposed TDP aims to:

- Demonstrate an advanced 4D (3D-Spatial + 1D-Temporal) ultrasound imaging system for non-invasive internal injury detection; bleedings or ruptures *beneath* surrounding tissues; and foreign particles (e.g. small shrapnel/bullets) *buried* from sight.
- Provide an ultrasound-based capability to facilitate *rapid triage* and *image-guided operations* in far-forward field operations for combat casualty care.



Advantages of Real-time 3D/4D vs 2D Ultrasound Imaging

- Minimal requirement for expert radiologist to diagnose injuries and abnormalities
- Better description of the relative locations of injuries and structures
- More accurate visualization during operations

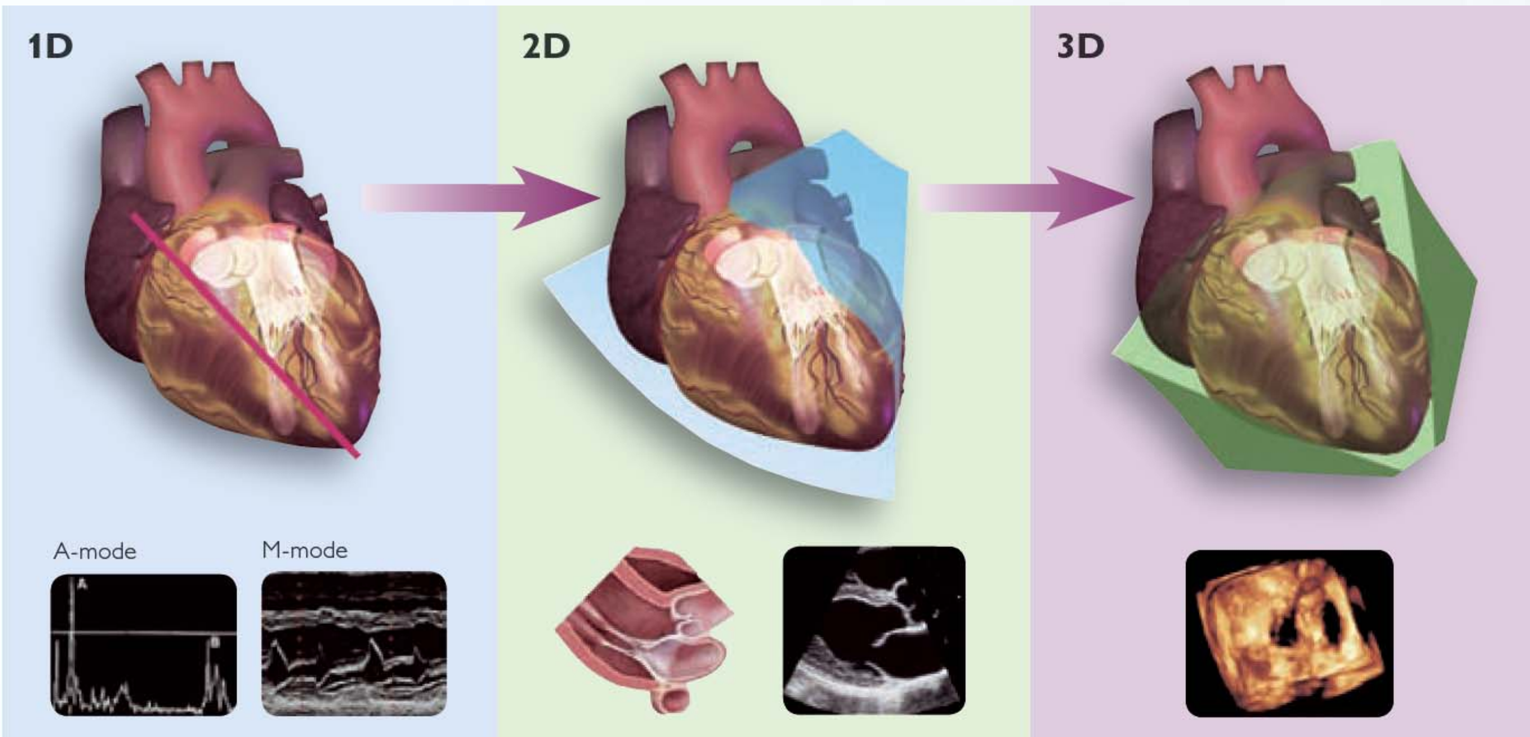


Figure adopted from article "Why Live 3D Echo" by Terry Hayes from Philips Healthcare website, http://www.healthcare.philips.com

Inherent Limitations of Current Technology

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- Real time 3D/4D ultrasound imaging systems, based on planar phase array probe, cannot be higher than 3.0 MHz because of the technological difficulties to cut the piezoelectric crystals.
- To achieve a high angular resolution and array gain required for medical imaging applications, it requires a large aperture with at least 4096 (64x64) channels to be processed coherently, which is a costly approach and with numerous technological challenges. It requires an enormous hardware complexity and prevents portability.

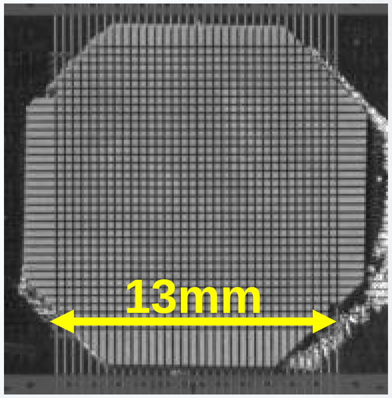
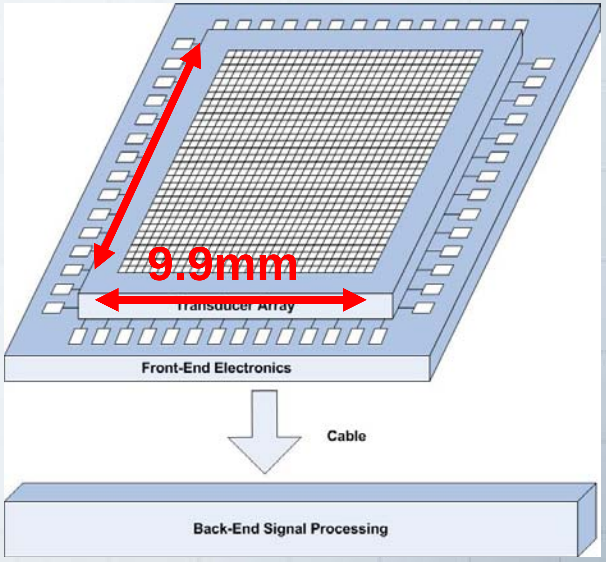


Image of a 36x36 elements planar array transducer developed at Duke University

DRDC's Proposed Solution

- DRDC's previous experimental 16x16 planar array ultrasound imaging development demonstrated that its proprietary 3D adaptive beamforming technology can achieve improved angular image resolution and array gains by a factor of 4. Thus, the deployed 32x32 array will have an improved resolution and array gain equivalent to a 64x64 planar array.



PUDIS planar array transducer design with 32x32 elements

Key Concept of DRDC Ultrasound Technology

Advantage of Parallel Computing with FPGA

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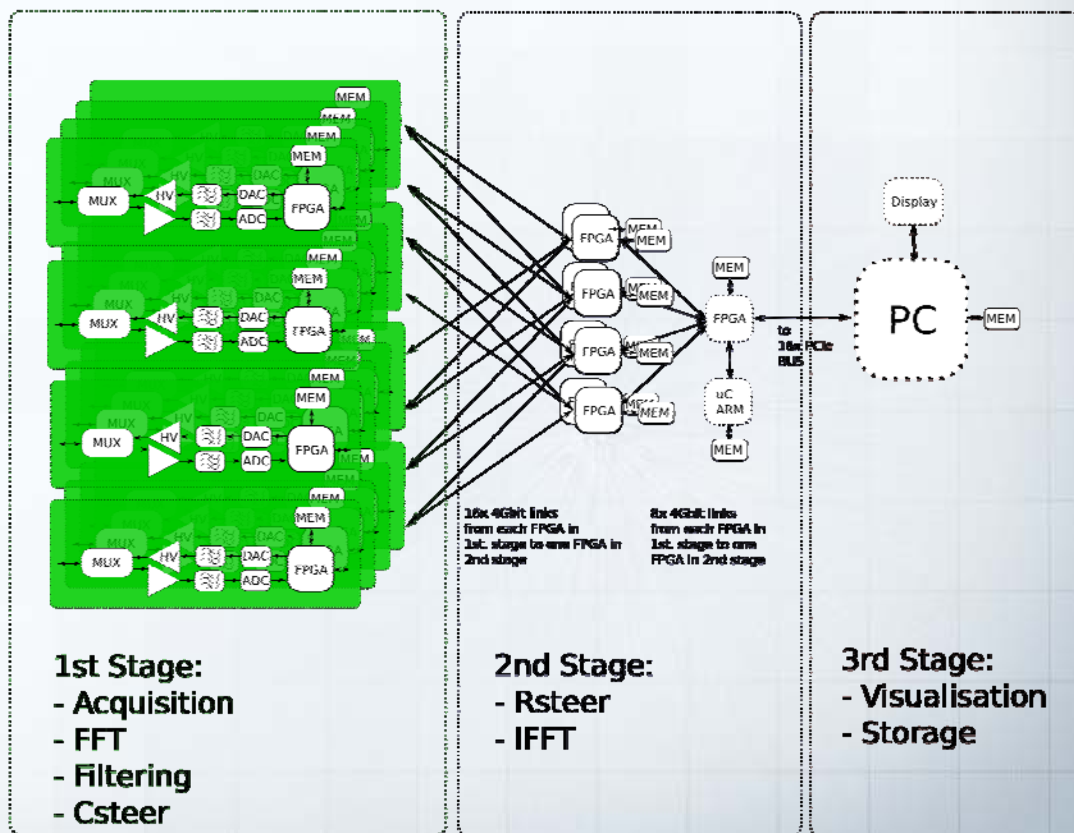
Amount of data needs to be processed in 1 second:

Precision x Samples x Channels x Snapshots x Volumes
14 x 4096 x 1024 x 16 x 21 = **19.44 Gbit**

- An average desktop PC takes about ***60 seconds*** to process ***1 volume***
- PUDIS's parallel processing architecture with FPGA is able to process ***20 volumes*** in ***1 second***
- Processing time is reduced by a factor of ***1200 times***



Key Concept of DRDC Ultrasound Technology

Phase Planar Array Illumination

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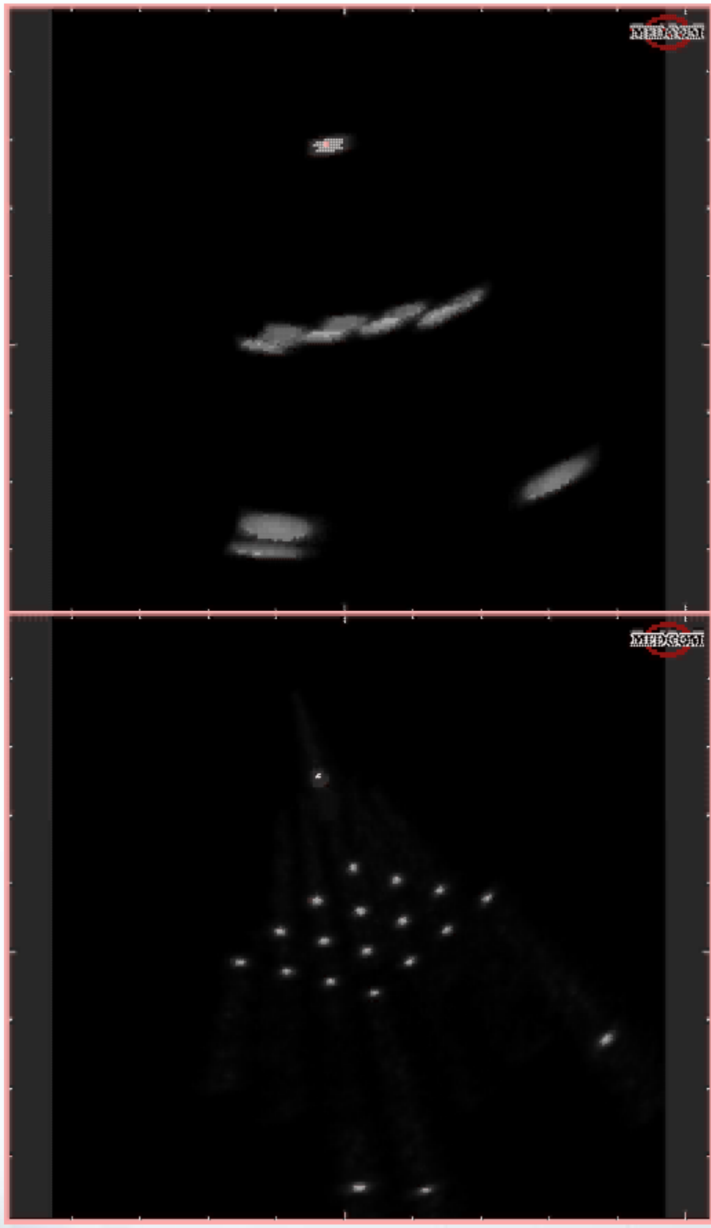
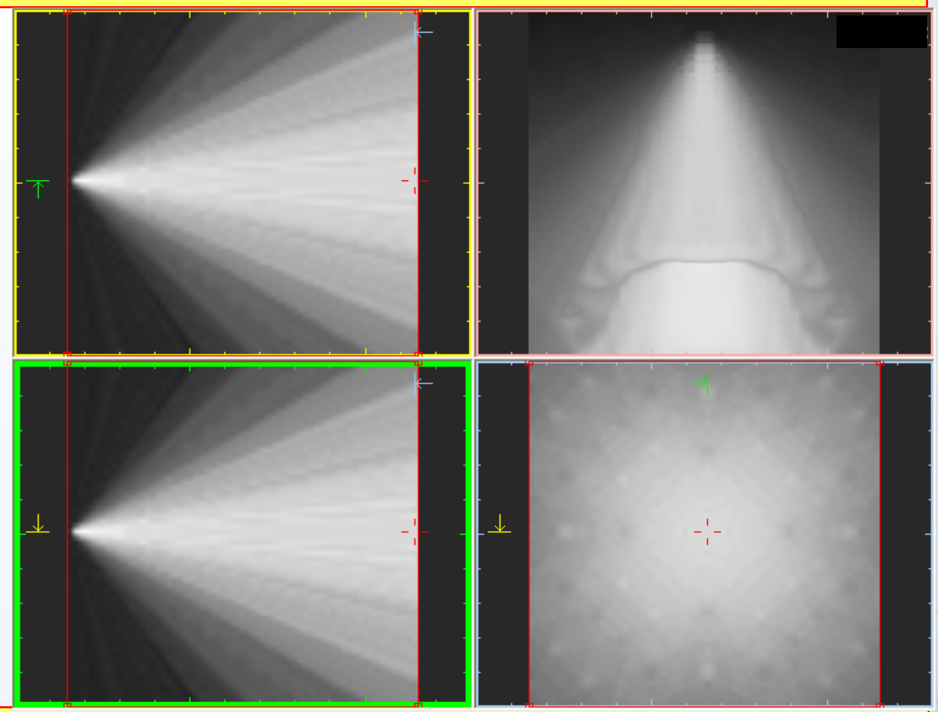


3D Adaptive Beamforming

- **Provides improved array gain performance for a 32x32 array by a factor of 4, which is equivalent in image resolution as that of a 64x64 array.**



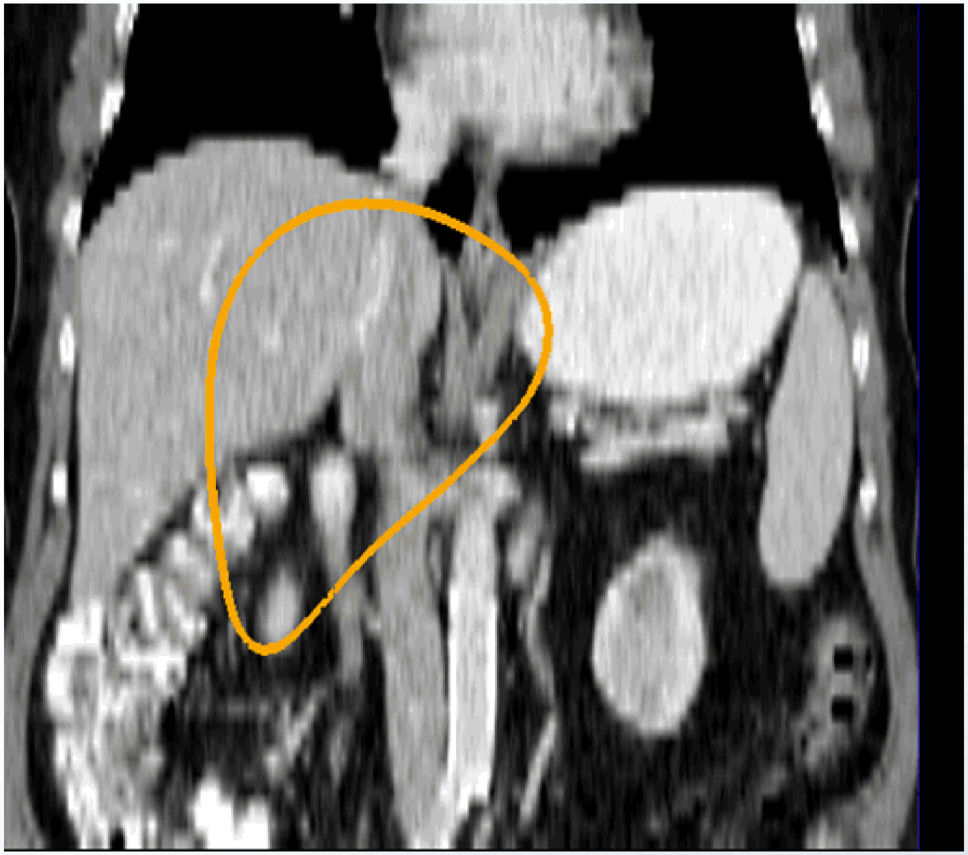
DRDC 3D Ultrasound System

- **Using a planar array of 32x32 *Sensors, single illumination patterns* and 3D *Beamformers* to obtain complete data acquisition for 3D Image reconstruction**

Exploitable Results (2)

Tools on Segmentation, Image Fusion to Facilitate Image Guided Automated Diagnostic Applications

Contour deformation: Affine Transformations



CF H Svcs Exploitation Objectives

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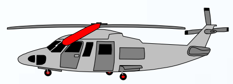
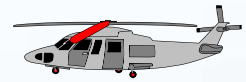
Continuous En Route Care

CASEVAC
1 Hour

TACTICAL EVAC
1-24 Hours


STRATEGIC EVAC
24-72 Hours

Battalion Aid Station "Level 1"

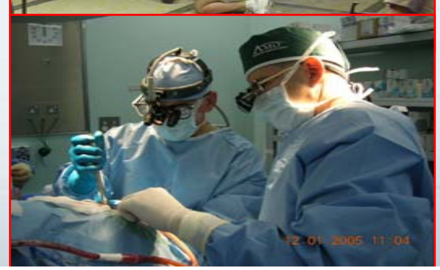
Forward Surgical Unit "Level 2"

In Theatre Hospital "Level 3"

Definitive Care "Level 4"



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