Ultrasound Dispersive Technology Providing Fluid-Solid Substance Classification for Security, Tomography 3-D Imaging for Surveillance and Non-Invasive Diagnosis for Brain and Organ Injuries

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Objectives

The purpose of this development was to demonstrate the capabilities of DRDC's adaptive signal processing technology and its implementation in the following low cost system applications:

- Ultrasound methodology to map dispersive properties of contained fluids, solids and tissues that can provide:
  - classification of fluid-solid substances for security screening, and
  - non-invasive diagnosis of brain injuries (e.g., edema, hemorrhage, brain swelling due to IEDs, stroke, etc.).
- Portable 3-D tomography imaging technology applied on:
  - ultrasound imaging for non-invasive rapid diagnosis and screening of injuries for mass casualties
  - non-destructive microwave computed tomography (CT) imaging for surveillance operations to map and track human activities in the interior of buildings and suspected terrorist activities.
- Image-Data Fusion and Vital Signs monitoring methodologies for Biometric applications using:
  - remote face recognition through high-resolution cameras
  - gait (i.e., silhouette and walking pattern) recognition
  - remote ECG tracking and pattern recognition.

which can be implemented in applications for homeland and IT security, remote identification of terrorist-suspects and authentication of personnel to allow access to highly secure environments.

The above experimental system applications, unified under an adaptive signal processing technology, have reached a state of maturity and are ready for Technology Demonstration Projects or Technology Acceleration Developments.

Relevance to CRTI Objectives

The present technology development has demonstrated that the relevant low cost system applications can address effectively the Chemical, Biological, Radiological, and Nuclear (CBRNE) Research and Technology Initiatives (CRTI) objectives in the fields of:

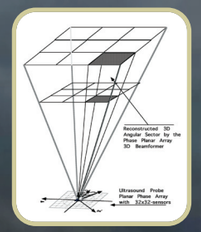
- Security systems for non-destructive screening of various kind of contained substances, an early stage detection of water-supplies contamination by terrorist groups and airport security.
- Non-Invasive Diagnostic portable, lightweight and battery powered devices for the first responders or combat medics to address requirements for 3-D ultrasound imaging of injured organs, early non-invasive diagnosis of brain injuries, trauma and for instances where there are no outwardly visible signs of brain trauma or injuries due to a blast and or an IED (Improvised Explosive Devices) attack or in a mass casualty field of operations.
- Non-Destructive Tomography Imaging and Surveillance of the interior of buildings, detection of buried sea-mines and close range (i.e., 1.5 km range) surveillance by means of 3-D sonar imaging of underwater areas of interest.
- Multi-sensor Biometrics with image-data fusion for remote identification of terrorist suspects in transit at airports, major stations, and ports, authentication of personnel entering highly secure areas and biometrics-based encryption.

Project Results

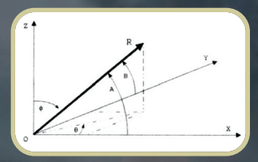
The 3-D ultrasound imaging system is composed of 5 major modules

1. The data-acquisition and coded pulse transmission hardware
2. The 16 x 16 element planar array ultrasound probe
3. The efficient software implementation of the 3-D beamformer
4. A scalable multi-node PC cluster
5. 3-D visualization software

Reference: Dhanantwari, A., Stergiopoulos, S., et.al., "An efficient 3-D beamformer implementation for real-time 4-D ultrasound systems deploying planar array probes", Proceedings of the IEEE UFFC'04 Symposium, Montreal, Canada, August 2004.

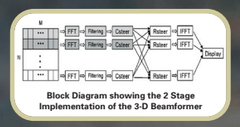


The Phased Array Transmit Function of the Planar Array Probe

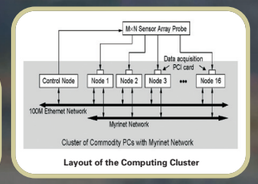


Definition of 3-D Beamformer's Parameters

The Multi-node Cluster

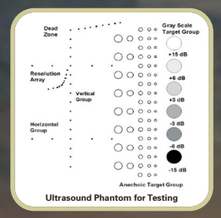


Block Diagram showing the 2 Stage Implementation of the 3-D Beamformer

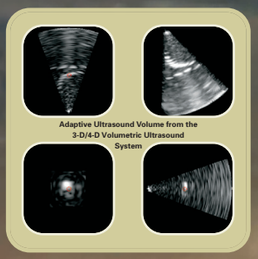


Layout of the Computing Cluster

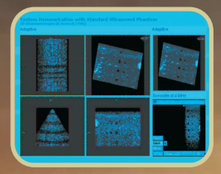
Experimental Results with Ultrasound Phantom

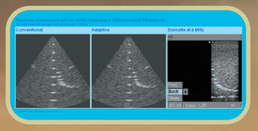


Ultrasound Phantom for Testing



Adaptive Ultrasound Volume from the 3-D/4-D Volumetric Ultrasound System





Ultrasound dispersive system for security screening of fluids, detection of water contamination and non-invasive diagnosis of brain injuries

It is composed of 3 major modules:

1. The Ultrasound probe
2. The Data Acquisition and coded pulse transmission hardware
3. The Signal processing and Display Unit

Reference: Stergiopoulos, S. and Wrobel, M. "Non-Invasive Diagnostic Ultrasound System Monitoring Brain Abnormalities", US Patent Application: 10/898,208, Dec-2001.

For Security Screening of Fluids

For Non-Invasive Diagnosis of Brain Injuries

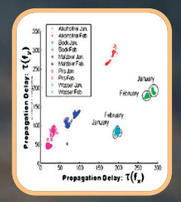
Principle of Operation

- Accurate estimation of time delay using phase information: $T_d = L/c$
- Variations in time delay estimates TL caused by changes in propagation velocity c
- The velocity c is defined as the ratio of the bulk modulus $yB(f)$ and the density p

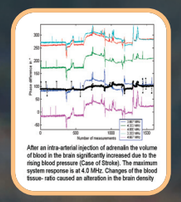
$c(f) = (yB(f)/p)^{1/2}$

- Dispersive properties of intracranial medium are expressed by a dependency on frequency of parameter $B(f)$

Fluid Classification

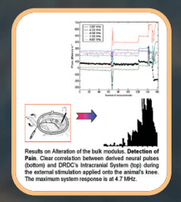


Animal Experimentation: Induced Stroke



After an intra-arterial injection of adrenalin the volume of blood in the brain significantly increased due to the rising blood pressure (Case of Stroke). The maximum system response is at 4.0 MHz. Changes of the blood tissue- ratio caused an alteration in the brain density

Animal Experimentation: Detection of Pain



Results on Alteration of the bulk modulus. **Detection of Pain.** Clear correlation between derived neural pulses (bottom) and DRDC's Intracranial System (top) during the external stimulation applied onto the animal's knee. The maximum system response is at 4.7 MHz.

Non-interfering wireless Ultra Wide Band Technology with capabilities for very high bandwidth of data transfer rate of the order of 1.5 Gbps

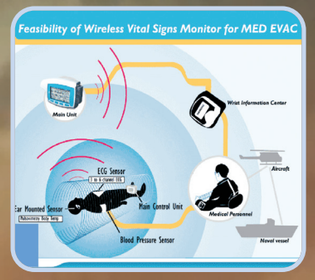
REQUIREMENT: Military MED-EVAC and Civilian Hospital Environments require wireless communications with minimum interference effects, and Compatibility with the military EMC standard MIL-STD-461E.

Existing Wireless Technologies and Products:

- Bluetooth (IEEE 802.15.1) does not meet requirements
- Zigbee (IEEE 802.15.4) does not meet requirements
- UWB (IEEE 802.15.3) meets requirements

This project development has demonstrated successfully a non-interfering UWB prototype as a non-interfering wireless technology on board a Black Hawk helicopter at the US Army Aeromedical Research Lab. Its capabilities for high bandwidth data transfer rate is essential to accommodate Surveillance requirements for remote monitoring of high resolution cameras and the devices resulting from the above system technologies.

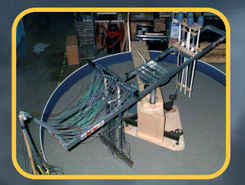
Reference: Liang Song, Dimitris Hatzinakos and Stergios Stergiopoulos, "Method and Apparatus of Adaptive Time-Frequency-Space Interference Cancellation for UWB Communications", US Prov. Patent Application, 60/801,072, Filed 18 May, 2006.



Non-destructive computed tomography for detecting buried sea mines and imaging interior of buildings

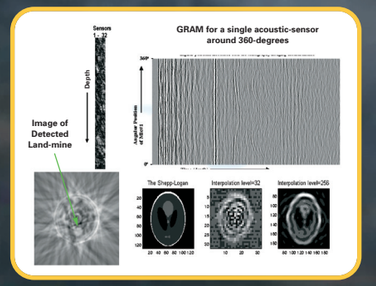
The objectives of a Technology Demonstration Project that is based on DRDC's acoustic CT technology include the completion of an industrial prototype system ready for field deployment.

Reference: Younis, W., Stergiopoulos, S., Havelock, D., Grodski, J., "Non-Destructive Imaging of Shallow Buried Objects Using Acoustic Computed Tomography", J. Acoust. Soc. Am., 111(5), 2117-2127, 2002.



Acoustic Tomography for Detecting Land Mines

Current State of DRDC's Adaptive Technologies



3-D Schematic of CT-Sonar Concept

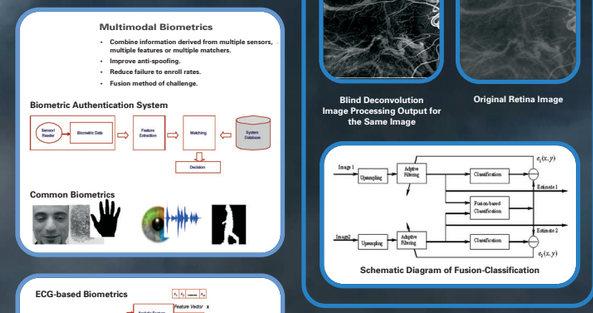
Computed Tomography for Surveillance

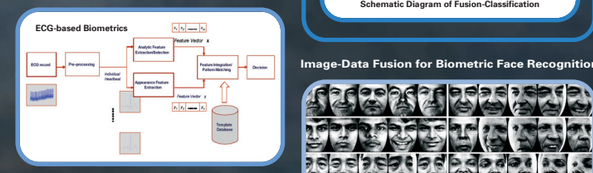
Microwave 95 GHz Non-Destructive Tomography Imaging and Surveillance of Building Interiors

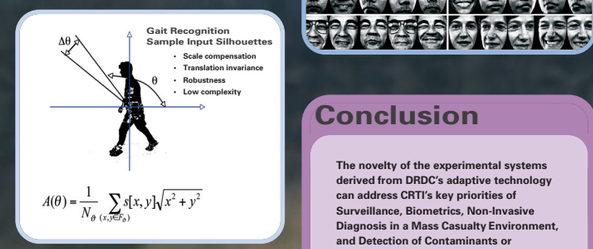
Image-data fusion processing and monitoring vital signs system technologies for Biometric Identification system applications

References: Boulougouris, N., Plataniotis, K. and Hatzinakos, D., "Gait reconstruction: A challenging signal processing technology for Biometric Identification", IEEE Signal Processing Magazine, pp 78-90, Nov. 2005.

Pinto, L., Dhanantwari, A., Wong, W. and Stergiopoulos, S., *"Blood Pressure Monitoring System Using Adaptive Interference Cancellation for Applications in Noisy and Vibration Intense Environments"*, Annals of Biomedical Engineering, 30, 657-670, 2002.







$$A(\theta) = \frac{1}{N_\theta} \sum_{(x,y) \in P_\theta} s[x,y] \sqrt{x^2 + y^2}$$

Image-Data Fusion for Biometric Image Enhancement Using Blind Deconvolution

Blind Deconvolution Image Processing Output for the Same Image

Original Retina Image

Image-Data Fusion for Biometric Face Recognition

Conclusion

The novelty of the experimental systems derived from DRDC's adaptive technology can address CRTI's key priorities of Surveillance, Biometrics, Non-Invasive Diagnosis in a Mass Casualty Environment, and Detection of Contaminants or unknown Substances. In summary, the devices that can be derived from DRDC's technology can be effective counter-terrorism tools to ensure safety by means of surveillance of air, land and sea transport systems and the early reliable medical diagnostic screening of injured personnel in a mass casualty environment.

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