UWB Short Range (Radar) Sensors

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Communication – Localization – Sensors

**Communication:**
- “New frequencies” for short range communication
  - FCC 2002: 3.1 - 10.6 GHz
  - Back to Marconi?
- Coexistence with other systems
- Simple systems and hardware

**Localization:**
- Unprecedented delay resolution (bandwidth!)
- Multipath resistance

**Sensors:**
- Material penetration (low frequencies!)
- More information on materials and shape of scanned media and bodies
UWB Spectrum Regulation - FCC

EIRP = effective isotropic radiated power

-30 dBm/MHz

-40 dBm/MHz

-50 dBm/MHz

-60 dBm/MHz

-70 dBm/MHz

-80 dBm/MHz

frequency [GHz]

1

10

critical gap for sensor applications

0.5 mW

-3 dBm

EIRP = -41.3 dBm/MHz

Rms value of field strength of 500 μV/m measured at 3 m distance and 1 MHz bandwidth
Basic UWB System Considerations

- Impulse radio, OFDM or direct sequence spread spectrum?
- Integrated system design example
  - Experimental system as used for all examples given
- Basic localization principles
- Radar imaging
Impulse excitation:

\[ y(t) \sim h(t) \quad \text{if} \quad x(t) \sim \delta(t) \]
Correlation Processing

Excitation: noise

Cross-correlation ~ IRF
Maximum Length Binary Sequence (MLBS)

Ideal 4\textsuperscript{th} order M-Sequence

\[ T_0 = N t_c \]

\[ t_c = 1/f_c \]

Number of chips: \( N = 2^n - 1 \)

Time-Bandwidth-Product: \( TB \approx 2^n \)

Auto correlation function

\[ 10 \lg(TB) \]

Correlation Gain!
Single Chip Demonstrator System in SiGe

V_{ee} = 3 \, V

Courtesy M. Kmec, TU Ilmenau
Experimental System (Baseband)

Transmit signal spectrum (not calibrated)

Direct wave

Cross-talk

System impulse response

IR, not calibrated
35dB dynamic range

IR calibrated
60dB dynamic range
Demonstrator System 3.5…10.5 GHz

- RF-clock
- Digital shift register
- MLBS
- 7 GHz
- Binary divider
- LO unit
- 1/2
- MLBS to sensor
- Complex Impulse Response Function
- Digital signal processing
- ADC
- T&H
- Base Band Processing
- IF – Front - End

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Basic Radar Signal Processing

- Radar echo depends on target size, shape, and material composition
- Desired target information: distance, location, orientation, speed, shape, material composition, recognition...

\[
\varepsilon = \varepsilon(x, y, z, t, \tau) \quad \mu = \mu(x, y, z, t, \tau) \quad \sigma = \sigma(x, y, z, t, \tau)
\]

\( \varepsilon \) permittivity, \( \mu \) permeability, \( \sigma \) conductivity, space coordinates \( x, y, z \), observation time \( t \), delay time \( \tau \).
Spatial Processing and Radar Imaging

Focused data

Cross range

Object

Time delay

Measured data

Measured data

Time delay

Focused data

Cross range

Object

distance [m]

depth [m]

Measured data

single scan contribution

Focused data
UWB Localization and Sensor Applications

• Localization of active devices (tags)
• Localization and recognition of passive objects
• Imaging of structures and environments
• Material characterization

• Non destructive testing
• Civil engineering and mining
• Short range navigation
• Industrial sensing
• Safety and security
• Automotive
• Biomedical engineering
• Law enforcement, military
• Search and rescue
Humanitarian Demining (GPR)

3 x 3 UWB array and metal detector

9 channel M-Sequence UWB Radar

Courtesy QinetiQ

TM62 Plastic AT mine

Courtesy MEODAT and QinetiQ
Humanitarian Demining (GPR)

APL and UXO Detection

“Wave penetration” into the soil

Courtesy Vrije Universiteit Brussels
(Demonstrating video)
Non-Destructive Testing in Civil Engineering

Experimental Set-up

Arrangement of 5 by 3 bricks
Detection of wall structures, artefacts, moisture

all bricks are dry

the central brick was exposed to water
Radar Sewer Tube Crawler

Antenna unit

Test field in preparation with foreign objects

- radar unit
- operation control
- angle sensor
- data interface
Radar Sewer Tube Crawler: Measurement example
Detection of human body activities: cardiac & respiratory

Measurement data with background subtraction

heart beat rate: 83

Slide 20

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MRI Image Enhancement

Tracking of heart and lung movement
Cancer Detection

In vitro measurement of a human lung during NaCl-Perfusion

Variation of water content by approaching the cancer

![Graph showing variation of water content](image-url)
Active Location Approach

Measured Example • cm (sub-cm) precision

- measured track
- actual track
- moved transmit antenna (bi-cone)
- receive array (Vivaldi antennas)

- circular wave front
- detected wave front
- Real antenna
- $\varphi = 90^\circ$
- $\varphi = 45^\circ$
- $\varphi = 0^\circ$
- $\varphi = -45^\circ$

- Y direction [m]
- X direction [m]
Active Location Approach

Measured example: 3D-positioning

sandbox

Vivaldi-Array

Demonstrating video
Passive Approach

Example

Moving target (box 0.5 x 0.1 x 0.5 m)

- Actual track
- Measured track

Transmit antenna (bi-cone)

Receive array (Vivaldi antennas)
Search and Rescue Applications

Detection of people buried by an avalanche

Detection of people buried by earthquake

Tracking of people behind the wall

Rescue personnel, injured persons in static environments
  • detection respiratory activity
  • detection cardiac activity
  • moving persons

Recognition of building structures
  • hidden rooms and cavities
  • wall structures
  • blocked entrance

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Imaging of Environments: Measured Example

- Rx1 and Rx 2: anchor nodes
- Tx: roaming illuminator node
- Direct and scattered wave separated
- Tx position track estimated from direct wave
- Image of environment calculated from scattered wave
Imaging of Environments: Measured Example

Rx1 contribution to the focused image - single snapshot

Focused image from Rx1 and Rx2 contribution

Estimated track of the Tx movement
"Bat-type" sensors are equipped with one Tx and two Rx antennas. No coherent cooperation of distributed sensors required. Sensor positioning maybe self contained. Additional positioning (inertial sensors or by anchor nodes) may help.

Correlation of single snapshots.
Imaging of Objects: Resolution
Localizing of people - through the wall

Measurement scenario

- Test object
- Wooden door
- Furniture
- 1st part of the track
- 2nd part of the track
- 3rd part of the track
- 4th part of the track

Dimensions:
- 500cm
- 30cm
- 200cm
Localizing of people - through the wall

Antenna arrangement

Measurement scenario in reality

Demonstrating video
Through Wall Detection of Breathing Activity

- Tx antenna
- Rx antenna
- Wooden door
- Brick wall
- 40cm
- 200cm

- 5 times deep breath
- slow
- 5 times deep breath fast
- 4 times flat breathing

Test object
Detection of buried people

Detection of Breathing and heart beat

Radar data after removing static scatterer

Backscattered signal modulated by rhythmic variations of the breast due to breathing

Radar data after enhancement of breathing activity

Breathing person

Breathing rate [Hz]

0.2 0.4 0.6 0.8 1.0 1.2

0 10 20 30 40 50

Propagation Time [ns]
Through-Wall Measurements

- Light concrete wall
- Wooden wall
- Bricks
- Timber
- Tile
- Floor
- Hand held device

Courtesy RADIOTECT project
Larvae detection

Hylotrupes bajulus

Measurement set-up

Bi-static radar

Wood with larva
Larvae detection

Radargram after Background removal

ROI (region of interest)

Movement of the larva

Round trip time [ns]

Normalised energy of ROI

Observation time [s]
Conclusions

- UWB sensor application offers clear advantage over other radar, optical and ultrasound sensors.
- Frequency regulation not optimal for sensor application.
- Low power, high clock rate integrated circuit technology required (SiGe).
- Huge absolute and relative bandwidth requires paradigm shifts from narrowband to wideband principles.
- Sensor cooperation and spatial distributed processing (sensor networks).
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Ultra-Wideband Radio Technologies for Communications, Localization and Sensor Applications