FORWARD SCATTER RADAR FOR REMOTE INTELLIGENCE OF BUILDING INTERIORS

Dr. W.E. van Rossum, Dr. Ir. J.J.M. de Wit
Backscatter Radar
Examples of Backscatter Experiments

Forward Scatter Radar
Forward Scatter Experiments

Future work
**BACKSCATTER RADAR: SAPPHIRE**

- 0.5 m resolution in 3D at 10 m distance
- Fully polarimetric aperture sampling
- MIMO array: 4 Tx elements, 8 Rx elements
  - → 32 virtual MIMO T/R elements
- Waveform: sequence of 16 FMCW sweeps
  - → 4 Tx positions x 4 polarisation combinations
SAPPHIRE: PROJECT

- Funded by EMRS-TDC
- Mapping of buildings with stand-off polarimetric FMCW SAR radar
- Drive by a building and build-up 3D building map
SAPPHIRE: RESULTS (2D) BUILDING MAPPING

- building map
- measurement
SAPPHIRE: MAPPING AND FEATURE EXTRACTION

- 3D imaging based on back projection
- Building feature extraction
  - building structure can be represented by principal scatterers
  - principal scatterers have different phase behaviour in 3D
  - phase behaviour can be used to identify and locate different scatterers
SAPPHIRE: RESULTS FEATURE EXTRACTION

corners
wall
building map
measurement
RIBA: PROJECT

- EDA-funded project, i.e., BAE Systems Advanced Technology Centre
- Tracking of moving people and transponders was shown to be promising
- By tracking over a longer period of time extra information about the inside of a building was obtained, i.e., doors used
- Multipath effects occur during tracking, further research is needed to suppress multipath reflections
RIBA: RESULTS PERSONNEL TRACKING

Stationary set-up:
Multi-room tracking
TRACKING

Forward Scatter Radar for Remote Intelligence of Building Interiors
Clusters of well-established tracks:

Position 1

Position 2
BACKSCATTER VS. FORWARD SCATTER

- Through-wall radar is a common technique for building mapping and inside-building tracking of people
  - typically operation is based on (monostatic) backscatter radar (BSR)
  - backscatter of people is low and many multipath reflections may occur in a cluttered environment
  - the monostatic reflection of a person and multipath reflections may be of comparable strength
    making reliable detection and tracking difficult

- Forward Scatter Radar (FSR) is based on the forward scatter of a person
  - for opaque objects, including humans, the forward scatter may be higher than the backscatter
  - the high forward scatter mitigates the effect of multipath reflections
SCATTER MECHANISMS

Forward Scatter Radar for Remote Intelligence of Building Interiors
FORWARD SCATTER CROSS SECTION

› Given the radar wavelength $\lambda$, the Forward Scatter Cross Section (FSCS) of an object is:

$$\sigma_{FSR} = \frac{4\pi A^2}{\lambda^2}$$

› If an object is opaque, the FSCS depends only on the area $A$ of the object

› Consequently, the use of stealth designs or Radar Absorbent Materials (RAM) does not reduce the FSCS

› This is the main reason Forward Scatter Radar is typically applied as ‘fence detection’
FORWARD SCATTER CROSS SECTION

› In literature, a human is typically modelled as a cylinder of height $H$ and diameter $D$, with area $H \cdot D$,

› Then the FSCS follows as: $\sigma_{FSR} = \frac{4\pi(HD)^2}{\lambda^2}$ and the BSCS follows as$^1$: $\sigma_{BSR} = \frac{\pi H^2 D}{\lambda}$

› For $H = 1.8$ m, $D = 0.5$ m and 12.5 cm wavelength, the FCS is 28.1 dBm and the BSCS is 16.1 dBm$^2$
  › The FSCS is a factor 16 higher than the (monostatic) BSCS

FORWARD SCATTER LOCALISATION

Approximately the resolution for backscatter is:
- driven by antenna length $L$

Assume resolution for forward scatter:
- diameter of first Fresnel zone

Resolution forward scatter and backscatter about equal:
- at 2.4 GHz and an object at 5 m: $L = 0.55$ m

$$\Delta x_{BSR} \approx \frac{\lambda}{L} \cdot R$$

$$\Delta x_{FSR} \approx \sqrt{2R \cdot \lambda}$$

$$L \approx \sqrt{\frac{\lambda R}{2}}$$
FSR DETECTION: SIMULATION

- In FSR the received signal is the sum of the direct signal and the signal scattered forward by an object.

- If the direct signal is stationary, changes of the received signal indicate the presence of an object.

- Because the forward scatter is relatively large the changes in the received signal are significant, allowing reliable detection on the basis of the received signal’s amplitude.

![Graph showing FSR detection simulation](image)
FSR DETECTION: FREE SPACE

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FSR/BSR DETECTION MEASUREMENTS
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The measurements have shown that reliable and consistent detection of people crossing the FSR baseline is feasible even in difficult through-building scenarios

However, in realistic through-building scenarios, due to multipath and the geometry, the signal power for FSR was lower than for BSR

The width of the FSR response was more narrow than the width of the BSR response

Combining FSR and BSR in a single system will yield the benefits from both scattering processes
ARTS: ACTIVE RANGING TRANSPONDER SYSTEM

- ARTS is a 2.4 GHz network of portable transponders for first responder location support inside buildings.
- Each transponder measures the distance to all other transponders using an FMCW-like technique.
- The transponders are not locked thus frequency and timing offsets lead to distance errors.
- Synchronisation and calibration is performed wireless to correct frequency and timing offsets and measure range and speed.
- All transponders communicate range data.
FUTURE WORK

- ARTS concept provides wireless synchronisation, communication and positioning functionality
- SAPPHIRE concept provides MIMO backscatter and forward scatter radar functionality
- Combining the ARTS and SAPPHIRE technologies would lead to an integrated RF solution for wireless synchronisation, communication, blue-force positioning and multistatic radar:

  **NEFRITE: iNside Edifice Forward-scattering Radar Integrated with Transponder Equipment**
Radar Technology

- AMBER: Reconfigurable
- EMERALD: Programmable
- SAPPHIRE: Polarimetric
- RUBY: Portable
- NEFRITE: Wireless
- DIAMOND: Distributed
- OPAL: Miniature
THANK YOU FOR YOUR ATTENTION

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