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Detection of Distorted IR-UWB Pulses in Low SNR NLOS Scenarios

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Outline

Outline

- Motivation and preliminary thought(s)
- Proposed algorithm
- Experiment
- Performance
- Summary and outlook

Niedersachsen

(a) Lower Saxony

(b) ERDF

Figure: Project funding

Motivation

- indoor localization *next big thing* in navigation
- IR-UWB enables high accuracy ToF (time-of-flight) ranging
- bottlenecks are NLOS (non-line-of-sight) effects (cf. [5])
- ensuring sufficient LOS (line-of-sight) links often not feasible
- frequent and critical NLOS case: penetration of material (typically walls)
  - distortion of pulse shape (cf. [4])
  - attenuation of signal energy
  - bias in ranging (cf. [2, 1])

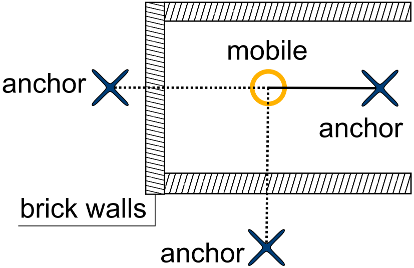


Figure: exemplary indoor localization scenario

Preliminary thought(s)

Pulse detection in frequency domain

- relative/different shift of containing frequencies
- reduced correlation coefficient with pulse template in time domain
- amplitude spectrum less affected than phase spectrum
- idea: correlation of amplitude spectrums often outperforms correlation in time domain

Distance candidates in ranging

- strong attenuation results in low SNR
- distinct determination of first received pulse not possible (cf. [3])
- detect serveral sample values with high probability to be an UWB pulse

Aim of the algorithm

Aim of the proposed algorithm:

(1) reduce the number of pulse candidates for a defined detection quality

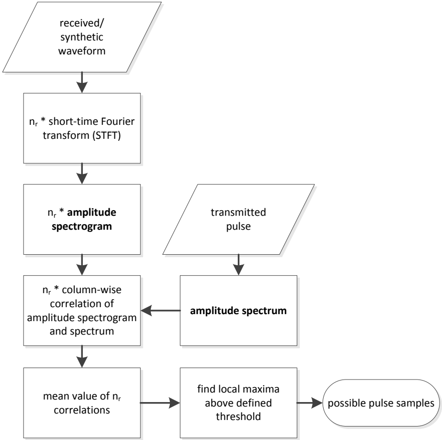
or

(2) improve the detection quality with a defined number of pulse candidates

Pulse candidate detection on |F|-correlation

Algorithm details

- core operation: short-time Fourier transform (STFT) on received signal
- STFT with different window sizes (reducing leakage effects)
  - e. g. $n_r = 3$: $\{1, 1.5, 1.7\} \cdot$ pulse width
- amplitude spectrograms S_{n_r}: $S_{n_r}[i,k] = |X[i,k]|^2$
- column-wise Pearson correlation with spectrum of pulse template:
  $\rho_{fS}[i] = \text{pcc}(\boldsymbol{C_i}, \boldsymbol{a_s}) \begin{cases} > 0 & \text{pcc}(\boldsymbol{C_i}, \boldsymbol{a_s}) \\ \leq 0 & 0 \end{cases}$



Pulse candidate detection on |F|-correlation

Algorithm details

- matrix of correlation values:

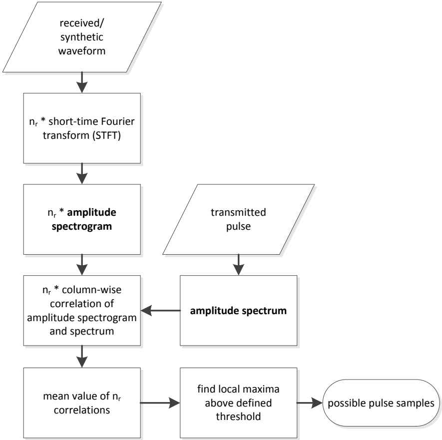
$$\rho_{f\,M}[i,u] = \begin{bmatrix} \rho_{f\,S_1}[1] & \rho_{f\,S_1}[2] & \cdots & \rho_{f\,S_1}[n_s] \\ \rho_{f\,S_2}[1] & \rho_{f\,S_2}[2] & \cdots & \rho_{f\,S_2}[n_s] \\ \vdots & \vdots & \vdots & \vdots \\ \rho_{f\,S_{n_r}}[1] & \rho_{f\,S_{n_r}}[2] & \cdots & \rho_{f\,S_{n_r}}[n_s] \end{bmatrix}$$

- column-wise average of coefficients:

$$\rho_{f\,A}[i] = \overline{\boldsymbol{R}_i}$$

- detection of local maxima:

$$Z[i] = \mathrm{sgn}[\boldsymbol{\rho_{f\,A}}']' \begin{cases} < 0 & \text{local maximum} \\ = 0 & \text{other fct. value} \\ > 0 & \text{local minimum} \end{cases}$$



Dielectric material parameters

Exemplary material: brick

- dielectric material parameters
- bandwidth from 2 GHz to 11 GHz
- based on Jing et al. [4]
- frequency dependent
- non-linear impact on propagation
  - amplitude constant
  - phase constant

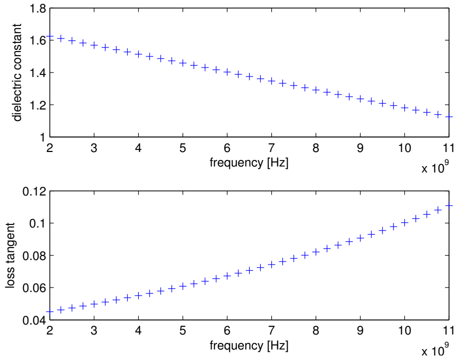
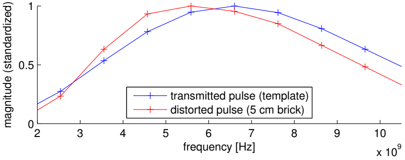
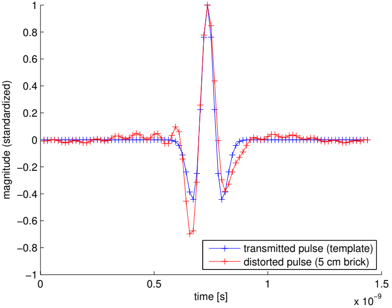


Figure: dielectric parameters material *brick*

Pulse distortion with wall of brick

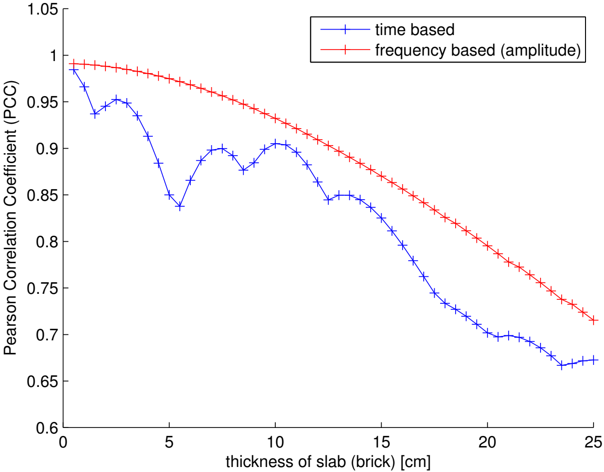
- distortion of pulse in time domain and amplitude spectrum
- wall of brick with thickness of 5 cm





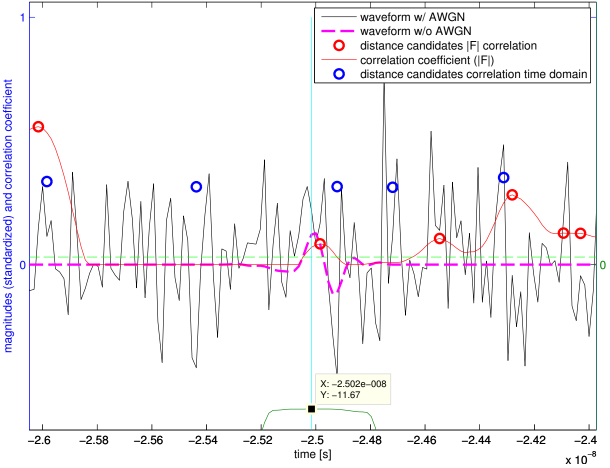
Comparison of correlation coefficients over wall thickness

- material: brick
- thickness: 0 cm to 25 cm
- **time domain**: discontinuous decaying correlation coefficient
- **amplitude spectrum**: continuous decaying correlation coefficient



Results from proposed algorithm (exemplary)

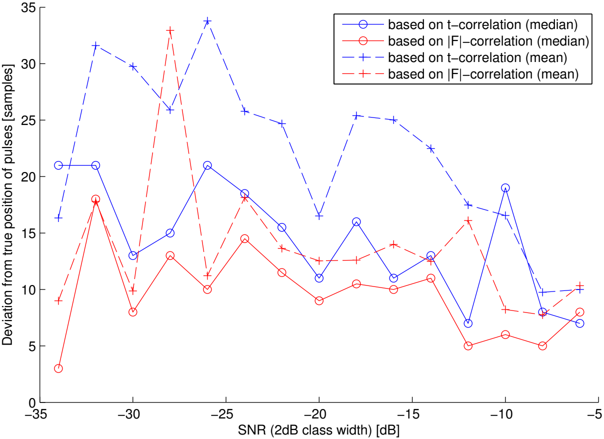
- 5 cm wall of brick
- ground truth of distorted pulse: $t = -25.02$ ns
- SNR: -11.67 dB
- red marker: candidates |F|-correlation
- blue marker: candidates t-correlation (matched filter)



Performance analysis (SNR)

Performance analysis

- quality criterion: deviation of closest candidate to ground truth
- SNR range: -34 dB to -6 dB
- cumulative improvement in this test case (brick, 5 cm, SNR range) is $37\,\%$
- means: with same number of candidates, detection accuracy increases by $37\,\%$ (average)



Summary and outlook

The aim of the paper was to depict a new approach for the detection of distorted and low SNR pulses in frequency domain to improve indoor localization.

Summary

- UWB pulses often strongly distorted and attenuated in indoor environments
- distortion reduces correlation in time domain
- correlation of amplitude spectrums instead can improve this
- experiment shows improvement up to $37\,\%$

Outlook

- analyse impact of angle of incidence on the wall
- further evaluation of the approach
  - other pulse shapes
  - different materials
- additional quality criteria
- runtime analysis

Literature

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NLOS identification and mitigation for localization based on UWB experimental data.
IEEE Journal on Selected Areas in Communications, 28(7), 2010.

Performance analysis (wall thickness)

- blue: general ratio of correlation coefficients $\left(\frac{\text{t-correlation}_{thickness}}{|\text{F}|\text{-correlation}_{thickness}}\right)$
- improvement follows course of general ratio
- different STFT windows results in additional improvement