FAST OBJECT LOCALIZATION USING SINGLE-CHIP UWB RADAR SENSOR [1]

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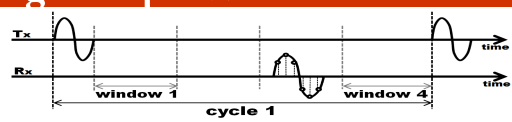
Introduction

- Goal: Minimize acquisition time to localize few objects using single-chip UWB radar sensor
- Motivation: less acquisition time increases
  - energy efficiency
  - time resolution for object tracking
- Existing CS-based UWB radar approaches [2] [3]
  - mostly theoretical focus
  - Integrate random-sampler to UWB circuit
- Applications
  - Object tracking in indoor/outdoor environment
  - Non-invasive breathing (respiration) monitoring

Single-chip UWB Radar Sensor [4]



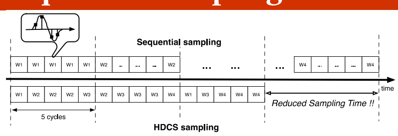
- Exploit ranging technique: 1-to-1 mapping between distance and roundtrip time of reflected pulse
- Provide energy efficient sampling architecture
  - activate the circuit only during a certain window
  - perform in-circuit averaging operation to achieve high SNR

Window identification ⟺ Object localization

- Exploit sequential sampling
  ① For every cycle, send a short-time pulse
  ② Measure reflections in a window over multiple cycles
  ③ Average measured signals within the window to increase SNR
  ④ Repeat (1)-(3) for all the windows
  ⑤ Threshold to identify window

Can we decrease the total sampling time ?

Sequential Sampling vs. HDCS



- Sequential Sampling (SS)
  - measure reflection within a single window
  - repeat it for every window
- Hardware-driven Compressed Sensing (HDCS)
  - aggregate reflections in multiple windows
  - reduce acquisition time to scan all the windows

How to combine multiple windows ?

Problem Formulation

- System Parameters
  - N_c : # of cycles
  - N_w: # of windows in each cycle
  - N_s: # of samples in each window
- Block-sparse signal, x in R^N, where $N=N_wN_s$[5]

$$x^T = [\underbrace{x_1,\ldots,x_{N_S}}_{x[1]},\ldots,\underbrace{x_{N-N_S+1},\ldots,x_N}_{x[N_W]}]^T$$

- Generalized matrix formulation
  - represent with Kronecker product

$$\Phi_{M\times N} = \begin{bmatrix} a_{(1,1)}I & \cdots & a_{(1,N_W)}I \\ \vdots & \ddots & \vdots \\ a_{(M_W,1)}I & \cdots & a_{(M_W,N_W)}I \end{bmatrix} = A_{M_W\times N_W} \otimes I_{N_S} \quad M_W < N_W$$

- SS: retrieve samples from single window

$$\Phi_{seq} = \begin{bmatrix} 5I & 0 & 0 & 0 \\ 0 & 5I & 0 & 0 \\ 0 & 0 & 5I & 0 \\ 0 & 0 & 0 & 5I \end{bmatrix}_{16\times16} = \begin{bmatrix} 5 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 0 & 5 \end{bmatrix} \otimes I_4$$

- HDCS: aggregate samples from multiple

$$\Phi_{HDCS} = \begin{bmatrix} 1I & 3I & 1I & 0 \\ 0 & 1I & 3I & 1I \end{bmatrix}_{8\times16} = \begin{bmatrix} 1 & 3 & 1 & 0 \\ 0 & 1 & 3 & 1 \end{bmatrix} \otimes I_4$$

- Two hardware-driven constraints on Φ
  - Non-negative integer entries
  - Equal row-sum ➔ sum of each row is fixed as N_c

How to design incoherent Φ satisfying two conditions ?

Proposed Approach (HDCS)

- Find A instead of Φ because

① A is incoherent
*② $a(i,j)$'s are NN** integers*
③ A has fixed row sum, N_c

➔

① Φ is incoherent
② $\varphi(i,j)$'s are NN integers
③ Φ has fixed row sum, N_c

- Exploit incoherent LDPC matrix[6]
  LDPC matrix satisfies two hardware driven constraints:
  (1) non-negative integer entries, (2) fixed row-sum
- Construct measurement matrix (Φ) using LDPC matrix (A)
- 2-step reconstruction for localization
  ① Reconstruct x using window-based reweighted L_1 minimization.

$$\min \| \sum_{j=1}^{N} W_i(j)x_i(j)\|_1 \ \ s.t. \ \ \|\Phi x - y\|_2 \le \delta$$

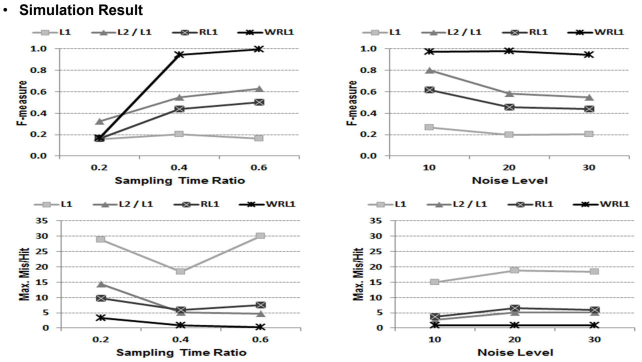
$$\text{, where } W_i[k] = \frac{1}{\|x_{i-1}[k]\|_1 + \epsilon}, \ k \in \{1,\ldots,N_W\}$$

  ② Identify windows containing reflections by

$$supp(x) = \{i \in [1,\ldots,N_W] : \|x[i]\|_2 > 0.001\}$$

Simulation Result

- Simulation Result



Achieve reliable target-localization with 40 % sampling time of sequential sampling and highly noisy measurements

Conclusion

- Minimize acquisition time to localize few objects using single-chip UWB radar sensor
- Design sensing matrix, Φ, satisfying hardware-driven constraints
  - Non-negative integer entries
  - Fixed row-sum of entries
- Propose non-linear reconstruction based on windows
  - Non-linear reconstruction of block-sparse signal
  - Robust to noisy measurements (< -15 dB)

References

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