Sandia National Laboratories

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Doppler Assisted Sensor Fusion for Tracking and Exploitation

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Outline

Introduction

Moving Emitter Challenge

Association Metric

Results

Conclusion

Introduction

- What is Sensor Fusion?
  - Sensor Fusion, is the fusion of sensors at the sensor level for information processing, not at the derived data level
- Advancements continue to be made in multi sensor processing
  - Software packages available for automated fusion of sensor metadata streams
  - Tools are avail able to query datasets at higher levels of abstraction
- Many multi-sensor platforms remain “serial sensor” prior to metadata fusion
  - e.g., one sensor queues full motion video (Optical)
  - Is there any thing being missed at the sensor level?
- DASF: Doppler Assisted Sensor Fusion
  - Addresses the challenge of quickly locating moving emitters
  - DASF is a new approach to fusing multiple sensors by leveraging Doppler derived range-rate signatures from disparate sensor modalities

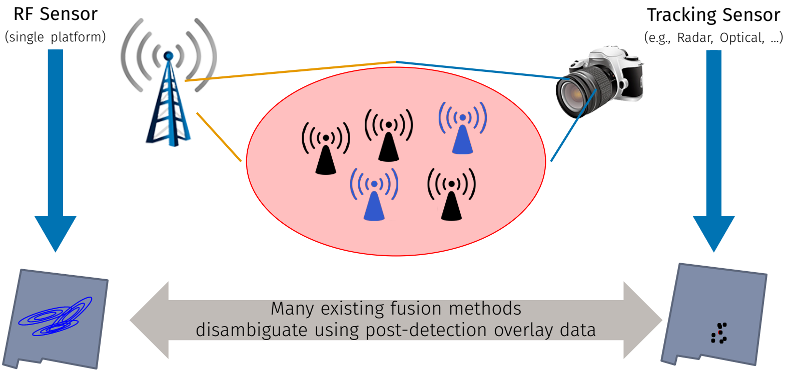
The Moving Emitter Challenge

- Locating a moving emitter using range only measurements is a difficult problem

Static RF emitter
geolocation is good given current techniques

Moving RF emitter > 2.5km error,
Little utility in congested areas

Current Precision Geolocation Methods



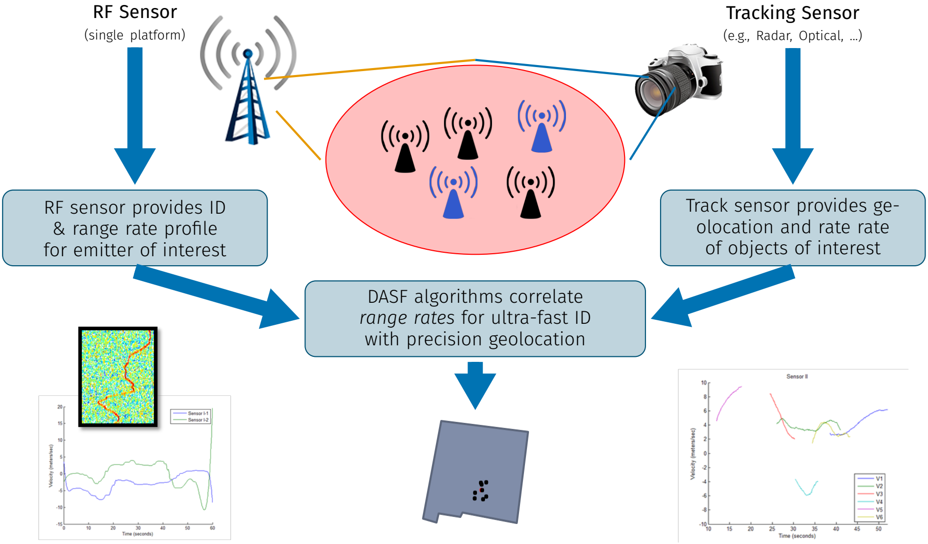
RF Sensor

- Insufficient geo accuracy for movers
- Sufficient identity information

Tracking Sensor

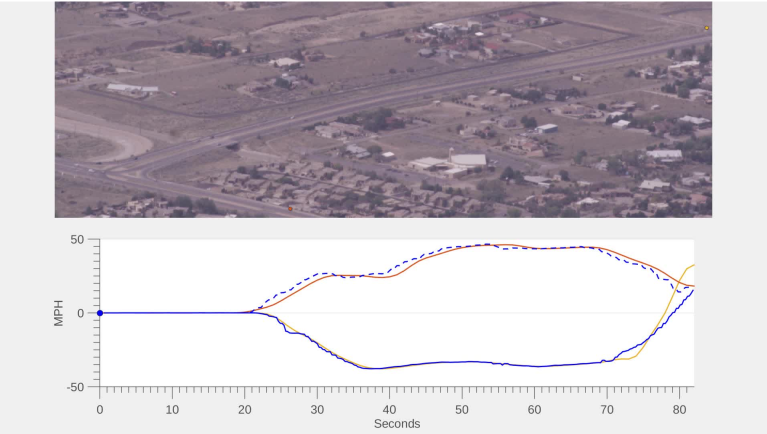
- Excellent geo accuracy for movers
- Insufficient identity information

DASF Approach



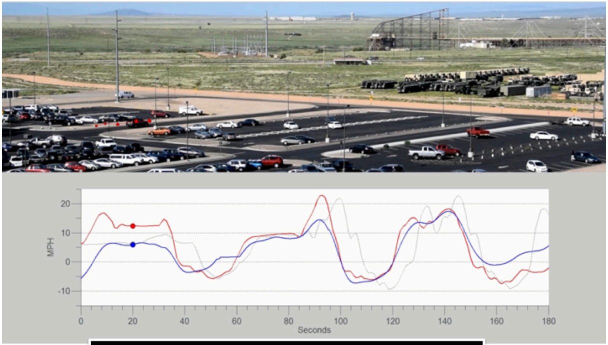
DASF Pairing Example: RF + Optical

- Two movers were tracked, each with non-cooperative emitters from 7km
- DASF sensor pairing:
  - RF sensor: A receiver was used to track the range rate signature of the RF emitters
  - Optical: A camera was used to track movers in the scene



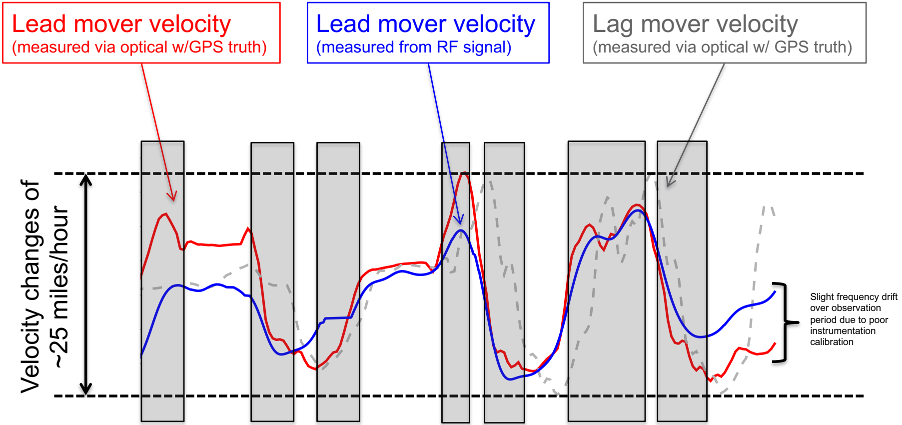
DASF Pairing Example: RF Emitter + Optical

- Two movers were tracked one with a non-cooperative emitter, one without
- DASF sensor pairing:
  - RF sensor: A surrogate receiver was used to track the range rate signature of an RF movers
  - Optical: A surrogate camera was used to track movers in the scene
- Which movers has the emitter?



Video: DASF RF + OPTICAL/GPS Association

Areas of Association

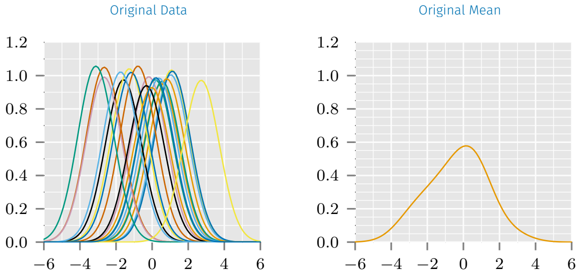


Lead mover has the emitter

Areas highlight in gray indicate change in velocity. These results suggest that algorithm will be effective for velocity changes on the order of 20mph or greater.

Association Metric

- Since the range rate profiles are observations of a function on an interval we can use functional data analysis
- Problem: Previous methods assume that the observed functions are temporally aligned, what if they are not
- How does this affect the analysis?
- Can we account for it?



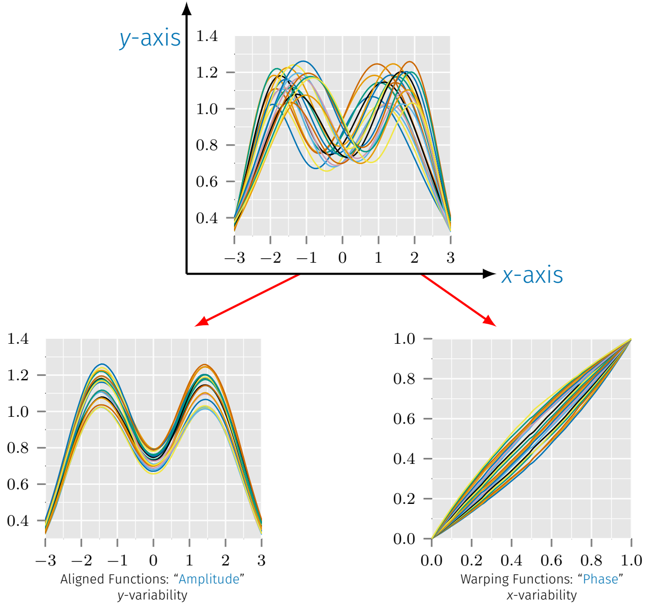
Approach

- Approaches: Two approaches to the temporal alignment (phase variability) problem
    1. Step-wise: Separate phase and amplitude components followed by estimation of sample statistics on the phase and amplitude, components, respectively
    2. Combined: Phase variability can be incorporated into the optimization to create a joint or elastic analysis
        - Elastic Principal Component Analysis
        - Elastic Functional Regression Model

References

1. J. D. Tucker, W. Wu, and A. Srivastava, "Phase-Amplitude Separation of Proteomics Data Using Extended Fisher-Rao Metric," Electronic Journal of Statistics, Vol 8, no. 2. pp 1724-1733, 2014.
2. J. D. Tucker, W. Wu, and A. Srivastava, "Analysis of signals under compositional noise With applications to SONAR data," IEEE Journal of Oceanic Engineering, Vol 29, no. 2. pp 318-330, Apr 2014.
3. J. D. Tucker, W. Wu, and A. Srivastava, "Generative Models for Function Data using Phase and Amplitude Separation," Computational Statistics and Data Analysis, Vol. 61, pp. 50-66, May 2013.

Functional Data Alignment / Phase-Amplitude Separation



Alignment of Functions (Phase-Amplitude Separation)

- [Srivastava et. al. (2011)] proposed a novel transformation of functional data which provides a proper metric for separation of phase and amplitude
- Let f be a real-valued absolutely continuous function with the domain $[0, 1]$
  1. Let elements of the group Γ play the role of warping functions as the set of boundary-preserving diffeomorphisms, $\gamma : [0, 1] \to [0, 1]$
  2. For any f, the operation, $f \circ \gamma$ denotes the time warping of f by γ
- Problem: Under the standard $\mathbb{L}^2$ metric,
  - The action of Γ does not act by isometries since $\|f_1 \circ \gamma - f_2 \circ \gamma\| \neq \|f_1 - f_2\|$
- Solutions:
  1. Use the *square-root slope function* or SRSF of f

$$q(t) = \text{sign}(\dot{f}(t))\sqrt{|\dot{f}(t)|}$$

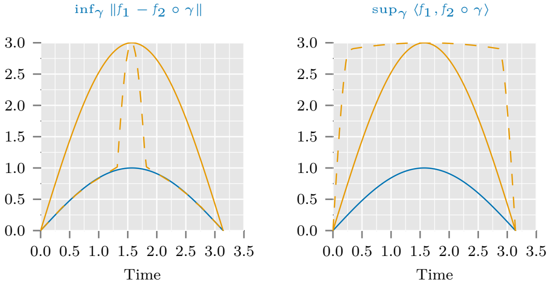
     where $\|q_1 - q_2\| = \|(q_1, \gamma) - (q_2, \gamma)\|$ and $(q_1, \gamma) = (q_1 \circ \gamma)\sqrt{\dot{\gamma}}$
  2. Leads to a distance on $\mathcal{F}/\Gamma$: $d_a(f_1, f_2) = \inf_{\gamma \in \Gamma} \|q_1 - (q_2, \gamma)\|$

Pinching Problem

- Why use the SRSF?
  - The $\mathbb{L}^2$ distance is a proper distance

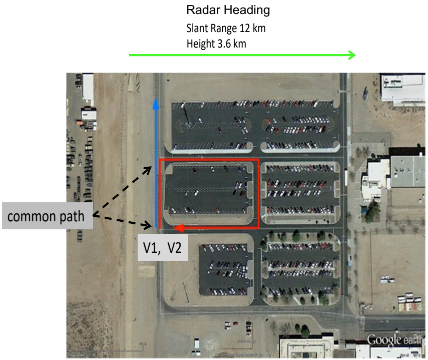
$$d_a(f_1, f_2) = \inf_{\gamma \in \Gamma} \|q_1 - (q_2, \gamma)\|$$

  - The action of Γ does act by isometries
  - Solves the pinching problem



DASF Experiment: RF Sensor + Radar

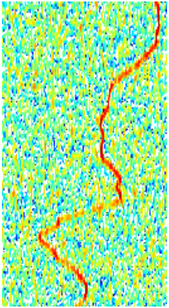
- Experiment Configuration
  - Emitter receiver co-located with radar
  - Emitter 1/Mover 1:
    - CW Center Frequency: f_c - 10kHz
  - Emitter 2/Mover 2:
    - CW Center Frequency: f_c + 10kHz
  - Radar
    - Single Antenna phase center
    - Five moving emitters in test area
- Experiment Goal
  - Demonstrate the ability to correlate emitter range rate track to radar range rate track
  - Which of 5 movers has each of the 2 emitters?



Mover (V1) configured with a 10 dBm emitter, straight path
Mover (V2) configured with a 20 dBm emitter, square path

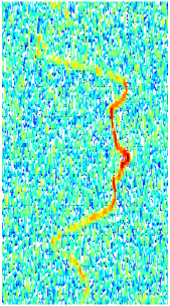
RF Sensor Rage Rate (RR) Tracks

Mover 1: emitter response straight path



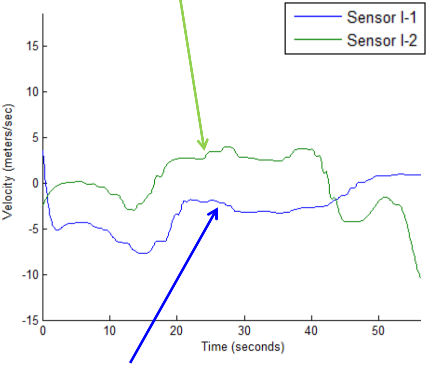
Emitter 1 spectrogram

Mover 2: emitter response square path



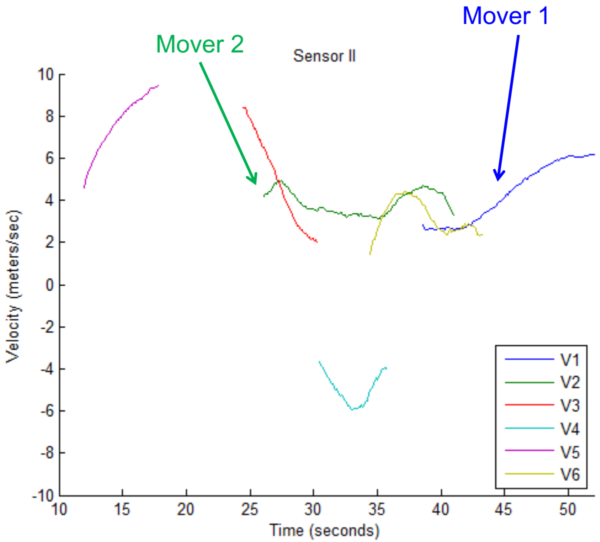
Emitter 2 spectrogram

RR measurement of Emitter 2 located on Mover 2 (square path)



RR measurement of Emitter 1 located on Mover 1 (straight path)

Sample Radar Map During Test



Association and Distance Matrix

Table: Fisher-Rao Distance between each pairing

	GEO 1	GEO 2	GEO 3	GEO 4	GEO 5	GEO 6
Emitter 1	0.005	1.8582	1.5076	1.9017	2.0601	2.0826
Emitter 2	4.4101	0.0056	1.9687	1.5607	1.5006	1.6857

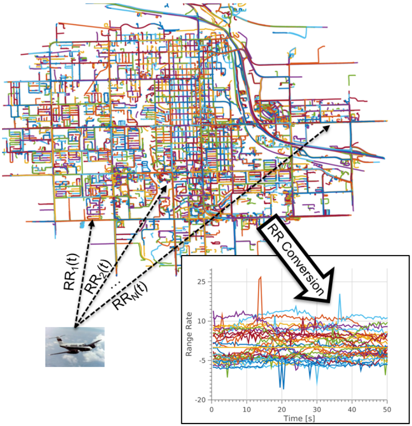
- Small distance value indicates that the mover range-rate is associated with the emitter range rate with high confidence
- This shows we can disambiguate for a small data set, what about a large data set with larger matches

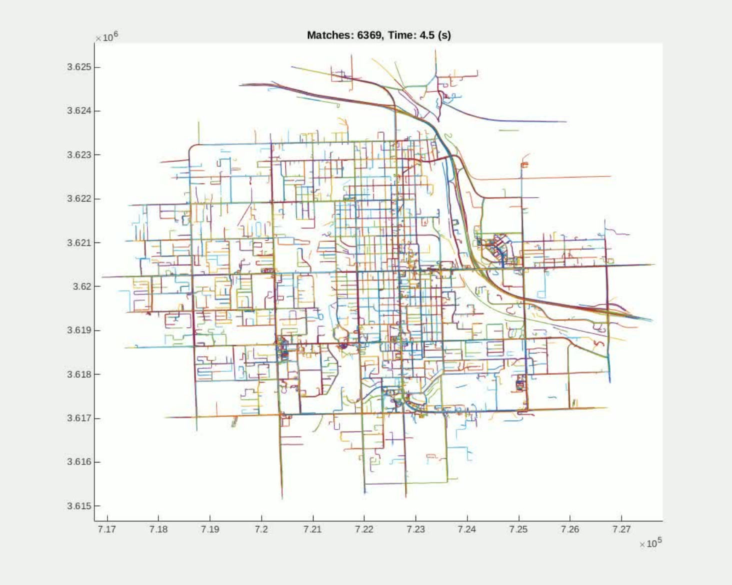
WAMI Large Dataset Disambiguation

- Large, high fidelity WAMI data set used to test potential DASF disambiguation performance
  - WAMI: Wide Area Motion Imagery
  - Tracks converted to range rate for a given platform position & trajectory
  - Single track selected as a surrogate “RF emitter” to test self-disambiguation

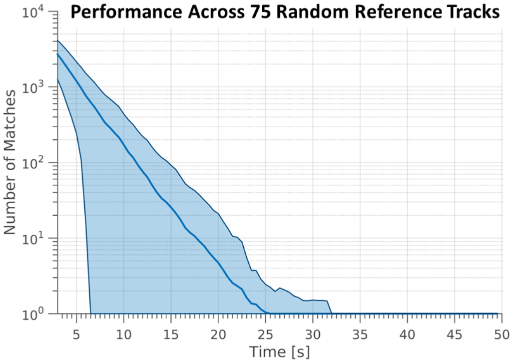
MASIVS Wide Area Motion Imagery (WAMI) data †

- **880 megapixel sensor, 25min data**
- **25,238 co-temporal tracks, 5sec→25min, 2Hz update**
- **All tracks converted to Range Rate (RR)**




Matches: 6369, Time: 4.5 (s)
×10^6
3.625
3.624
3.623
3.622
3.621
3.62
3.619
3.618
3.617
3.616
3.615
7.17
7.18
7.19
7.2
7.21
7.22
7.23
7.24
7.25
7.26
7.27
×10^5

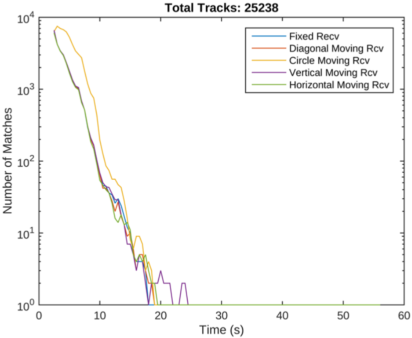
Range Rate Only Self-Disambiguation Results



- DASF Range Rate Only Self-Disambiguation Performance:
  - 25238 tracks $\rightarrow$ 1 track in $\sim$25 seconds
  - $\sim$25 seconds represents best case wide-area performance with MASIVS, compared to 35 seconds using standard $\mathbb{L}^2$
- If paired with RF range rate tracks, disambiguation time would increase depending on emitter frequency & track fidelity

Platform Trajectory Variation

- Range rate only algorithm performance very similar across fixed and variable platform trajectories



Conclusion

- DASF addresses vexing moving emitter problems
- Solution through true sensor fusion at the sensor data level
- Utilizes “elastic” Fisher-Rao metric which can handle time-misalignment and sensor misalignment
- Early proof-of-concept experiments and results show promise of future work
  - Initial work was accomplished under Sandia LDRD
  - Early disambiguation time (25s) suggests quick disambiguation using range rate profiles
- Future Work
  - Align range-rate curves and test fPCA and model construction
  - From constructed models, cluster and classify range-rate profiles

Questions?

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