VELOCITY UNFOLDING IN NETWORKED RADAR SYSTEM

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1. INTRODUCTION

It is well known that for the weather Doppler radar there is an inverse relationship between maximum unambiguous velocity and the maximum unambiguous range. Employment of various techniques, such as staggered PRF or transmitter phase encoding, can alter this relationship and improve the range and velocity bounds. However, even with these schemes standard weather Doppler radars' maximum unambiguous velocity rarely exceeds 50 m/s, a speed that is regularly exceeded by aircrafts and extreme weather phenomena, such as tornados, targets of increasing interest for weather Doppler radars [1], [2].

In case of the sensor network environment, such as one deployed by the Center for Collaborative Adaptive Sensing of the Atmosphere CASA in Oklahoma [3], we can take advantage of the fact that observed velocities project differently on different sensor nodes and consider estimation of velocities that exceed the maximum unambiguous velocity of a single radar.

In a networked environment, velocity folding can be thought of as a set of discrete solutions of a set of linear equations, which are the combinations of all the considered, folded and unfolded, cases of all of the observing nodes. Due to the bandwidth constraint and synchronization issues, the moment data is only available for real-time network operation, which invariantly limits the potential of unambiguous velocity estimation. However, under the assumption of certain velocity distributions and with knowledge of measurement uncertainties, the estimated velocity can be found as the one that falls within the range of the measurement accuracy.

This paper presents an algorithm that derives the vector velocity estimate in a radar network environment considering the velocities that well exceed the maximum unambiguous velocity of its observing sensor nodes. At first, analytical derivation with underlying assumptions is presented and then simulation results are shown and discussed. This unfolding vector velocity algorithm is based on maximum likelihood theory and operates on first three spectral moments. Also, it can possibly operate in real time, where the number of considered velocity foldings would be proportional to available computational power. As seen in theory and algorithm simulation, this inversion calculation can provide a solution for velocity detection of a broader range of velocities than the nodal maximum unambiguous velocity.

2. FORMULATION SUMMARY

The particular combination of folded and unfolded velocities of respective nodes in a radar network, \( \vec{\nu}_{\text{R}_i} \), can be calculated from the vector of measured mean radial velocities, \( \bar{\vec{\nu}}_R \), as

\[
\vec{\nu}_{\text{R}_i} = \bar{\vec{\nu}}_R + 2 \ F_i(\cdot) \vec{\nu}_{\text{R}_{\text{max}}} ;
\]

where \( \vec{\nu}_{\text{R}_{\text{max}}} \) is vector of maximum unambiguous velocities, \( F_i \) is \( i \)th column of the folding coefficient matrix, \( F \), and the operator \( (\cdot) \) represents element multiplication operation. Resulting combinations can be used to build a set of linear equations which, through employment of maximum likelihood theory and least squares estimator [4], would yield to the vector of estimated target velocities. These target models, with consideration with velocity folding, can be projected back onto the observing nodes to find resulting radial velocity models, \( \vec{\nu}_{\text{R}_{\text{mi}}} \).

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Comparison of measured nodal radial velocities $\tau_{R_i}$ to radial velocity model $\tau_{R_{mi}}$ shows the error involved with use of particular target velocity estimate $\tau_{T_i}$. Employment of the weighted minimum square error estimator where each of the velocity differences are weighted by the error involved with each of the nodal measurements, yields the optimum vector velocity estimate

$$\hat{\tau}_T = (A^T \text{Cov}^{-1}_{\tau_R} A)^{-1} A^T \text{Cov}^{-1}_{\tau_R} \min_i \left\{ \sum_{R=1}^{N} \left( \frac{\tau_{R_i} - \tau_{R_{mi}}}{\sigma^2_{\tau_R}} \right)^2 \right\}$$

where $A$ represents matrix transformation of observing geometry and $\text{Cov}_{\tau_R}$ is a positive definite measurement covariance matrix which diagonal represents a vector of the measurement variances of $\tau_R$.

3. SIMULATION RESULT EXCERPT

![Fig. 1. Probability distribution field of algorithm estimated velocity of a Gaussian target $\tau_T$ with $|\tau_T| = 90 \pm 28m/s$ and angle($\tau_T$) = $47 \pm 17^\circ$ employing three nodes positioned around the target with received signal powers of 12, 8 and 5 dB considering 100 samples and maximum unambiguous velocity of $48m/s$.]

4. REFERENCES


