“Signal Processing Based Distortion Mitigation in Interferometric Radar Angular Velocity Estimation”

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Abstract:

Interferometric angular velocity estimation is a relatively recent radar technique which uses a pair of widely spaced antenna elements and a correlation receiver to directly measure the angular velocity of a target. Traditional radar systems measure range, radial velocity (Doppler), and angle, while angular velocity is typically derived as the time-rate change of the angle measurements. The noise associated with the derived angular velocity estimate is statistically correlated with the angle measurements, and thus provides no additional information to traditional state space trackers. Interferometric angular velocity estimation, on the other hand, provides an independent measurement, thus forming a basis in $\mathbb{R}^2$ for both position and velocity.

While promising results have been presented for single target interferometric angular velocity estimation, there is a known issue which arises when multiple targets are present. The ideal interferometric response with multiple targets would contain only the mixing product between like targets across the antenna responses, yet instead, the mixing product between all targets is generated, resulting in unwanted ‘cross-terms’ or intermodulation distortion. To date, various hardware based methods have been presented, which are effective, though they tend to require an increased number of antenna elements, a larger physical system baseline, or signals with wide bandwidths. Presented here are novel methods for signal processing based interferometric angular velocity estimation distortion mitigation, which can be performed with only a single antenna pair and traditional continuous-wave or frequency-modulated continuous wave signals.

In this work, two classes of distortion mitigation methods are described: model-based and response decomposition. Model-based methods use a learned or analytic model with traditional non-linear optimization techniques to arrive at angular velocity estimates based on the complete interferometric
signal response. Response decomposition methods, on the other hand, aim to decompose the individual antenna responses into separate responses pertaining to each target, then associate like targets between antenna responses. By performing the correlation in this manner, the cross-terms, which typically corrupt the interferometric response, are mitigated. It was found that due to the quadratic scaling of distortion terms, model-based methods become exceedingly difficult as the number of targets grows large. Thus, the method of response decomposition is selected and results on measured radar signals are presented. For this, a custom single-board millimeter-wave interferometric radar was developed, and angular velocity measurements were performed in an enclosed environment consisting of two robotic targets. A set of experiments was designed to highlight easy, medium, and difficult cases for the response decomposition algorithm, and results are presented herein.

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