A Comparison of the Combining Methods for Phase-based Composite RFID Ranging

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Abstract—**This poster investigates the use of a phase-based, Dual-Frequency Continuous-Wave (DFCW) and Continuous-Wave (CW) composite radar for RF backscatter ranging. Several data fusion algorithms are studied and their performances compared. The experimental results show that, in strong line-of-sight environments, accurate, unambiguous ranging results can be achieved by the DFCW/CW composite ranging technique, based on a proper data fusion algorithm.**

I. INTRODUCTION

Localization of a passive radio frequency identification (RFID) tag has drawn significant attention, recently. A variety of ranging schemes have been investigated including phase-based techniques using continuous wave (CW) radars, multi-frequency continuous wave radars (MFCW), and a combination of a dual frequency continuous wave (DFCW) radar and a CW radar (i.e., a composite DFCW/CW radar). The composite DFCW/CW radar requires that the range estimates from the DFCW and CW radars be combined to form the final range estimate. This poster compares several existing DFCW/CW combining methods and presents a new method. The methods are compared using backscatter phase measurements taken at 5.8 GHz. The following paragraphs summarize the different ranging approaches, the composite DFCW/CW combining methods, and describe the measurement setup and results.

By tracking the phase difference between the transmitted signal and the signal reflected back from the tag, a CW radar can measure a relative distance very accurately, depending on the system frequency. However, it is known that a phase ambiguity exists if the distance to be measured is larger than a half wavelength. To extend the unambiguous distance, a MFCW radar can be used. An MFCW radar [1], [2] usually includes at least three system frequencies, among which the pair with the smallest frequency difference determines the maximum unambiguous range and the pair with the widest bandwidth gives the fine distance estimate.

A phase-based composite DFCW and CW ranging technique was proposed in [3] and [4]. The DFCW/CW composite ranging technique is different from the traditional MFCW technique in the sense that it uses the DFCW range estimate to resolve the ambiguity in the CW radar, and the CW results to find the fine distance estimate. Theoretically, a DFCW/CW composite radar can provide a much more accurate distance estimate than a conventional MFCW radar. The DFCW/CW composite technique has been experimentally demonstrated for some short range applications where high accuracy (on the millimeter level) is required, provided a dominant line of sight (LOS) is available [4]. Examples of such applications include entertainment (e.g., game controllers and human computer interaction) and motion capture/tracking systems.

One of the challenges for the DFCW/CW composite technique lies in how to combine the DFCW and CW range estimates. A straight-forward combining method is to determine the CW ambiguity integer k_1 directly based on the DFCW range estimate d_{2f} [3]. Although simple, the *direct combining method* generally requires high accuracy (i.e., the maximum Absolute Error (AE) must be smaller than $\lambda_1/2$) for the DFCW radar which, excluding multipath effects, requires either complicated hardware for accurate phase measurements or a large frequency separation Δf.

A *Minimum Mean Square Error (MMSE)* based data fusion algorithm was proposed in [4] which helps relax the bandwidth requirements. In the MMSE based data fusion algorithm, the CW range estimate is adjusted by $n\lambda/2$ to fit the DFCW range estimate. Here, λ is the wavelength of the selected CW radar and n is a testing integer number. Various integer numbers are tested and the best integer number is identified when the mean square difference between the DFCW and the CW distance estimates is minimized as the tag is moved through space.

The MMSE-based data fusion algorithm has been shown useful when the space averaging of the DFCW range error is less than $\lambda/4$. It is shown that this condition can be satisfied when a strong LOS is available, which typically occurs at short distances. The MMSE based algorithm, however, gives discontinuous errors (on the order of half wavelength) if the space averaging of the DFCW range error is larger than $\lambda/4$. An alternative combining method, which does not have discontinuous error changes, is the *general MMSE* (G-MMSE) fusion algorithm. Like the MMSE algorithm, n is chosen by minimizing the difference DFCW and CW range estimates as the tag moves through space, but is allowed to take non-integer values.

II. MEASUREMENT SETUP

We carried out measurements using a spread spectrum backscatter system purchased from Southern States, LLC. A photograph of the system and the measurement environment is

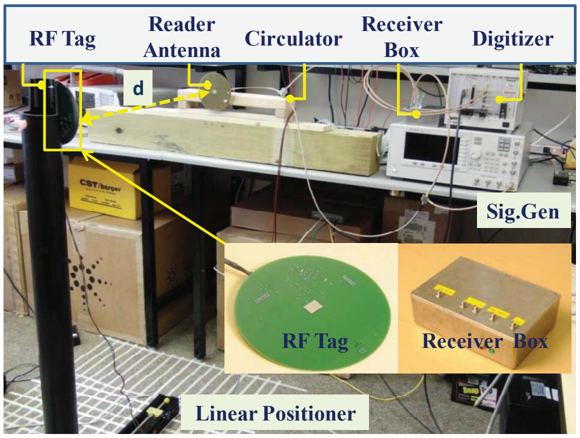

Fig. 1. The experimental setup for the DFCW/CW ranging measurements [4].

shown in Fig. 1. An Agilent PSG E8257D signal generator was used to generate the required system frequencies and the RF tag was a custom, semi-passive backscatter tag that modulated the backscatter with a 6-bit, maximal-length, pseudo-random code. A linear positioner was used to accurately control the distance between the tag and the reader antenna. The linear positioner was programmed to move 300 steps, at a step size of 2.54 mm, away from the reader antenna. At each step, the I/Q voltages output from the direct conversion box were digitized (Adlink PXI-9816H) and recorded by a computer for post processing.

III. MEASUREMENT RESULTS AND ANALYSIS

The measured distance errors based on different data combining methods are shown in Fig. 2. The system bandwidth for the DFCW radar is 50 MHz. The positive and negative quarter-wavelength bounds are also plotted as references. It is apparent that DFCW ranging is relatively coarse and DFCW/CW composite ranging (either based on the MMSE or G-MMSE methods) is more accurate. Fig. 2(b) is a Y axis zoomed-in view of Fig. 2(a). Due to the narrow bandwidth that has been chosen, the DFCW radar range estimate is not sufficiently accurate to resolve the ambiguity in the CW range estimate. As a result, the MMSE based composite radar gives a discontinuous distance estimate, as shown in Fig. 2(b) at the distance around 0.4m. However, the distance output based on G-MMSE method is smooth. The distance discontinuity in the MMSE distance occurs whenever the G-MMSE ranging error curve crosses the quarter-wavelength bound.

It is also shown in Fig. 2(a) that the composite ranging based on the direct combining method shows a relatively large error. This is caused by the coarse range estimate from the DFCW radar. In order to clearly show the small details, the large errors from the DFCW ranging and the direct combining based composite ranging have been removed in Fig. 2(b).

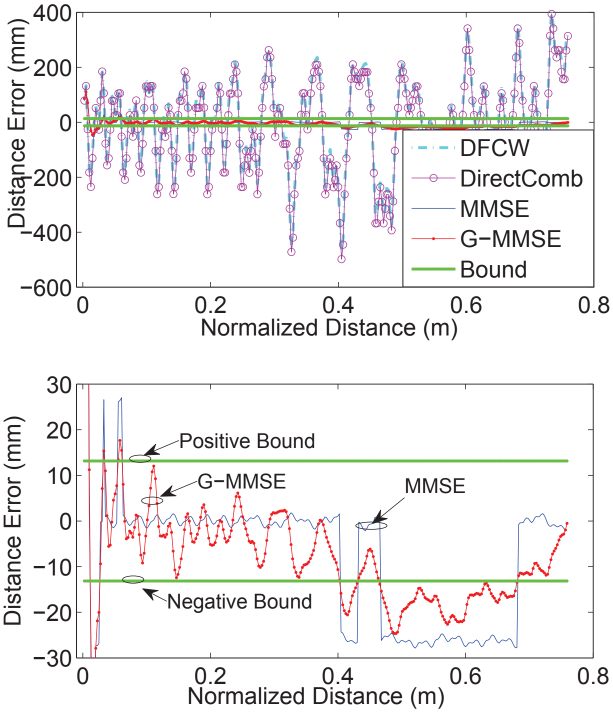

Fig. 2. Measured ranging errors for a DFCW radar and a composite DFCW/CW radar using the direct combining, MMSE and G-MMSE combining methods for both (a) a zoomed-out and (b) zoomed-in views.

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