Precise Radial Velocity Estimation Using an FMCW Radar

Andreas Haderer #1, Philipp Scherz #, Andreas Stelzer #

Institute for Communications Engineering & RF-Systems, Johannes Kepler University
4040 Linz, Austria
[1] a.haderer@nthfs.jku.at

***Abstract*— This contribution addresses radial velocity estimation with a frequency-modulated continuous-wave (FMCW) radar system. The estimator we propose aligns the up- and downchirp information of adjacent sweeps including the phasing of the chirps. The resulting one-dimensional signal depends on the radial velocity and can therefore be used for estimation purposes. Because the phase information between nearby chirps is preserved, the accuracy is seriously increased compared to estimators that evaluate only the frequency shift due to the Doppler effect. Additionally, the range of velocities that can be estimated without ambiguity constraints is extended considerably when compared to a standard range-Doppler procedure.**

I. INTRODUCTION

Estimating radial velocity is an important task in many operational fields of radar systems. In tracking applications, for instance, accurate knowledge of radial velocity is crucial in order to improve the tracking performance. The Doppler effect allows the radial velocity to be determined with high precision when a continuous wave (CW) radar with constant transmit frequency is used. In the case of frequency-modulated continuous-wave (FMCW) radars, the Doppler effect manifests itself as an additional frequency shift in the intermediate frequency (IF) signal [1]. To distinguish between the range-dependent frequency term and the Doppler shift, a pair of up- and downchirps can be used to extract the velocity information. Due to the short measurement time i.e., equal to the duration of one pair of up- and downchirp, the achievable accuracy is low. Range-Doppler (RD) algorithms use the phasing between adjacent chirps to estimate the radial velocity [2]. The increased observation time allows accurate estimates of the velocity component [3]. Unfortunately, these algorithms suffer from ambiguity problems: At RF frequencies (e.g., 77-GHz, as used in automotive applications), the range of velocities that can be estimated without ambiguities is extremely small. The algorithm we propose aligns the Doppler shift observed during adjacent up- and downchirps, causing the FMCW radar to behave like a CW system with constant transmit frequency. Hence, the ambiguity problem is reduced dramatically, and at the same time high accuracy is achieved.

II. FMCW RADAR SYSTEM

A block schematic diagram of a typical monostatic FMCW radar system is shown in Fig. 1. A voltage-controlled oscillator (VCO) in the transmit path generates the transmit signal $s_\mathrm{t}(t)$. The waveform consists of multiple successive up- and downchirps. The instantaneous frequency of the transmit

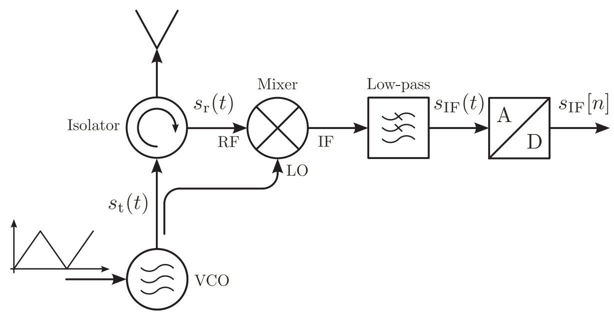

Fig. 1. Block diagram of a monostatic FMCW radar system. A VCO generates the transmit signal $s_\mathrm{t}(t)$, which is also used to down-convert the received signal. The de-ramped receive signal is sampled and utilized in further processing steps.

signal $f_\mathrm{t}(t)$ is depicted in Fig. 2. During an upchirp, the frequency is increased linearly, starting at the lower frequency f_0. The slope of the ramp, referred to as chirp rate, is given by $k_\mathrm{f} = B/T$, where B denotes the signal's bandwidth and T corresponds to the chirp duration. Assuming an ideal radar channel, the receive signal $s_\mathrm{r}(t)$ is a damped and delayed replica of the transmit waveform

$$s_\mathrm{r}(t) = \delta\, s_\mathrm{t}\left(t - \tau(t)\right) = \delta\, s_\mathrm{t}\left(t - 2r(t)/c_0\right), \qquad (1)$$

where δ denotes the attenuation and $\tau(t)$ is the round trip delay time (RTDT). The time delay is given as twice the instantaneous distance $r(t)$ divided by the propagation velocity of the electromagnetic wave c_0. In this paper, it is assumed that the targets exhibit a radial velocity component v_r. Thus, the time-dependent distance between the radar and the target is given by

$$r(t) = r_0 + v_r t, \qquad (2)$$

where r_0 refers to the distance at the reference time $t = 0$.
In an FMCW radar, the received signal is down-converted with part of the transmit signal - a method known as de-ramping. The filtered output signal of the mixer, referred to as IF signal, is used for further processing. To obtain a suitable signal model, the following mapping of the continuous time axis t is applied during M upchirps that are used for signal