Millimetre Wave Radar Imaging of Mining Vehicles

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Abstract— **This paper considers some of the complexities in regard to generating 2D and 3D radar images of mining infrastructure. It examines issues with range interpolation in multi scatterer environments and a method of modelling radar returns from vehicles.**

I. INTRODUCTION

For a decade we at the Australian Centre for Field Robotics have been using both 2D and 3D imaging radars to produce images of mining infrastructure including vehicles such as haul trucks and 4WDs, draglines and rope shovels [1, 2].

It has become clear that the process of generating images of metal targets comprising multiple scatterers is determined by the complex interaction of both target and radar characteristics.

II. RADAR SYSTEMS

A common set of hardware shown in Fig. 1 has been developed around a custom-developed FMCW front-end operating at 94GHz [3]. This unit can be configured for any sweep from a few μs up to tens of ms and for chirp bandwidths up to 2GHz. A 12bit ADC synchronised with the chirp and sampling at 1.25MHz followed by the usual windowing and spectral analysis algorithms performs the range gating function.

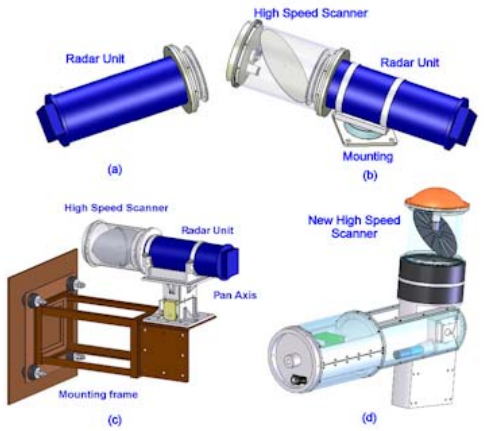

Fig. 1: Radar sensors developed from a common module for (a) range only radar, (b) 2D radar for profiling, (c) 3D radar for outdoor imaging and (d) 3D radar for insertion through a bore-hole [4]

For profiling or other 2D applications, a swash-plate mirror scanner is positioned within the beam and scans the beam over 360° as it spins. The light-weight mirrors are balanced so that they can be spun at up to 20rps without significant distortion to the reflecting surface or vibration. The top speed of the mirror is governed not only by the dynamics of the structure but also by the mirror motion which induces Doppler shift and consequently spreads the echo spectrum and reduces the effective range resolution.

For example, for the mirror moving at 20rps, the speed at the periphery of a 0.15m diameter mirror is 9.4m/s. This results in a Doppler shift of

$$f_d = \frac{2v}{\lambda} = 5.9\text{kHz}$$

As half of the mirror is travelling towards the target, and the other half away, the received signal will be spread by a maximum of double this (11.8kHz). The distribution of this frequency spread is determined by weighting the linear distribution of the Doppler shift across the mirror by the mirror area and the taper on the illuminating antenna beam.

For optimum performance the rotation speed should be sufficiently low that the total frequency spread is less than the width of a single range bin.

Flat mirrors that maintain the pencil-beam are used for profiling while shaped mirrors that produce a fan-beam are used for 2D reflectivity based imaging. A shaft encoder on the mirror produces an output synchronised with the range data to produce 2D polar measurements (R,θ) for each target detected within the beam.

The addition of a pan mechanism that rotates the complete radar/mirror assembly shown in Fig. 1c and d produces the third measurement axis. An angle encoder on the pan axes in conjunction with the other two measurements produces 3D polar measurements (R,θ,ϕ).

III. RANGING ALGORITHMS

The range resolution of a radar system is defined as the radial distance between two targets of equal amplitude that can be resolved as separate targets. It is well known that this is a function of both the transmitted bandwidth, and in the case of a FMCW system, the linearity of the transmitted chirp [5].

A. *Range Interpolation*

In the case of a single point-target isolated in space, interpolation using the amplitude of the central FFT bin, and those adjacent can be used to improve the measurement range accuracy to a few centimetres for a bin size of a meter or so.

For the three bins described by the points $(-r,a_1)$, $(0,a_2)$, (r,a_3) where r is the width of a bin and a_n is the amplitude of