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RANGE OBSCURATION MITIGATION BY ADAPTIVE PRF SELECTION FOR THE TDWR SYSTEM*

Sandra C. Crocker

MIT/Lincoln Laboratory
Lexington, Massachusetts 02173-0073

1. INTRODUCTION

The Federal Aviation Administration has recently awarded a contract for the procurement of 47 Terminal Doppler Weather Radar (TDWR) systems to be sited near high traffic airports. These systems will collect and process Doppler radar data that will be used by fully automated algorithms to identify hazardous meteorological wind shear events in real time (eg., microbursts and gust fronts.) This information will then be conveyed to aircraft pilots in order that potentially hazardous takeoffs or landings be averted.

In a pulsed Doppler weather radar, one of the most serious causes of data quality degradation is due to range aliased echoes from distant storms [3]. This range contamination can occur in the immediate vicinity of a meteorological hazard, possibly obscure the event, and thus decrease the probability of detecting it. In other instances, range contaminated data can present a radar signature similar to that of a wind shear hazard, and perhaps cause an algorithm to issue a false alarm. In order for the TDWR system to achieve a high probability of detecting meteorological hazards, while maintaining a low probability of false alarms, an effective means of dealing with range contamination is required.

An adaptive procedure by which to select the radar's pulse repetition frequency (PRF) has been developed as a primary means by which to minimize range contamination within the operationally significant coverage area of a TDWR system. This procedure will be developed within this paper and a quantitative assessment as to the anticipated effectiveness of this technique in the TDWR system will be provided.

2. BACKGROUND

TDWR systems will be tasked with identifying short lived, yet extremely hazardous wind shear phenomena known as microbursts, as well as the longer lived phenomena, gust fronts. Microburst surveillance is to occur within the immediate vicinity of the airport runways (typically within a 10 km radius of the airport center), while gust front surveillance covers a much larger geographical area (typically within a 60 km radius). The purpose of the PRF selection technique is to provide two optimal PRF values; one is to be used by the radar while collecting the data for microburst identification, the second while collecting the data for gust front identification. These PRFs are to be selected so as to minimize the area contaminated by range folded echoes within the two respective surveillance regions. (The data quality degradation attributed to these range folded returns is subsequently based on the relative signal strengths of the in-trip and out-of-trip weather.)

A TDWR testbed radar facility, configured and operated by MIT Lincoln Laboratory [4], has collected radar measurement data and exercised meteorological identification algorithms in support of the TDWR development effort over the past several years in a variety of geographical locations, most recently in Denver, CO. This testbed facility is comprised of a pencil beam radar which radiates at 2865 MHz, with a wavelength of approximately 10 cm. In order to ensure reasonable Nyquist intervals for the measurement of radial velocities associated with typical weather phenomena, this S-Band testbed radar operates at PRF values of from 700 to 1220 Hz. The corresponding unambiguous range intervals are calculated as 214 and 123 km, respectively. Assuming that distant storms as far away as 425 km may be detected by this radar, this span of PRF values could result in range contamination from 2nd, 3rd, and possibly even 4th trip distant weather echoes, depending on PRF and location of the storm.

The TDWR system will radiate at approximately 5650 MHz, and the resulting 5 cm wavelength implies an inherent reduction in the ability of the sensor to unambiguously measure a storm's radial velocity. To help compensate for this reduction at the C-Band frequency, a higher set of PRF values will be required over those currently used at the TDWR testbed. PRF values as high as 2000 Hz are anticipated, which results in unambiguous range intervals as short as 75 km. This means that obscuration from 2nd, 3rd, 4th, and possibly even 5th and 6th trip may be experienced in the TDWR environment, and providing an effective means by which to deal with this potential obscuration presents a significant challenge.

3. ADAPTIVE PRF SELECTION

During the collection of high quality Doppler data, a TDWR sensor will operate at PRF values that have been selected based on an adaptive procedure utilizing low PRF measurements of the distant weather

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situation [1]. At a rate of once every five minutes, reflectivity information will be gathered on storm cells which are located out to a distance of approximately 460 km from the radar. This distant weather information is then mapped into the available set of PRF values from which will be selected the PRFs for subsequent use. The mapping procedure is illustrated in Fig. 1. Here one sees range from the radar plotted as a function of PRF value, where the various curves denote first, the unambiguous range interval, followed by nth trip foldover bounds. For purposes of illustration, a high priority region is defined to be from 0 to 25 km from the radar, and the subsequent shaded regions depict nth trip potential obscuration to that region as a function of PRF value.

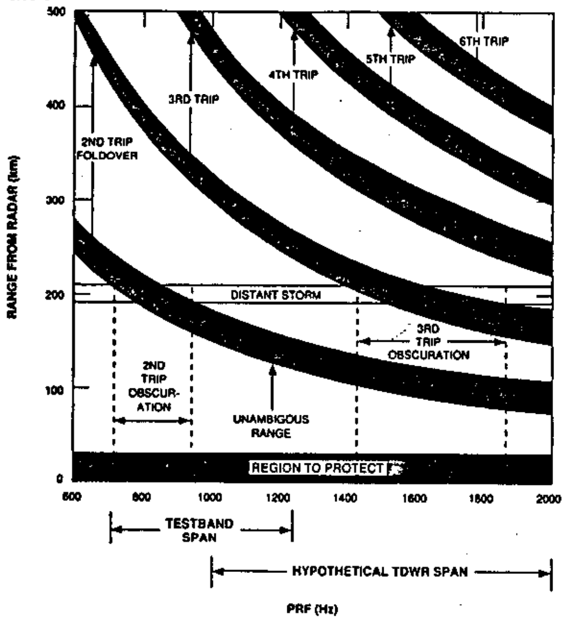

Figure 1. Adaptive PRF selection. The intersection of the lines containing the distant weather with the curves defining the nth trip foldover bounds indicate which PRF values will result in range contamination to the high priority region.

A hypothetical storm is located in this figure, centered approximated 200 km from the radar and spreading 10 km in either direction. The PRF selection algorithm maps this storm information into the PRF domain so as to provide an assessment of obscuration conditions within the high priority region as a function of PRF value. Those PRFs which would result in 2nd trip obscuration from this storm within the high priority region, as well as those PRFs which would result in 3rd trip obscuration, are so indicated. After mapping all such identified storms into the PRF domain, the technique selects that PRF which minimizes the obscuration to the high priority region. (As discussed later, the technique is further expanded to include obscuration minimization over *multiple* priority regions.)

PRF values between 600 and 2000 Hz are illustrated on the above figure. The operational version of the algorithm at the TDWR testbed considers only PRFs between 700 and 1220 Hz, as these values represent the available S-Band set. The TDWR PRF set, however, is expected to be a discrete set of values between 1000 and 2000 Hz. Figure 1 provides a means of visualizing the anticipated increase in range contamination due to operating at the higher PRF set.

4. EFFECTIVENESS OF ADAPTIVE PRF SELECTION

A comprehensive investigation covering various aspects of the adaptive PRF selection technique has recently been completed [2]. Two of the goals of this investigation were to provide a quantitative assessment of the effectiveness of the technique at the S-Band TDWR testbed sensor, as well as a quantitative assessment of the anticipated effectiveness of the technique for the C-Band TDWR system.

Every five minutes during normal data gathering exercises, the TDWR testbed radar surveys the distant weather situation using a low elevation, 350 Hz PRF scan with full 360-deg azimuthal coverage. This procedure was initiated at the testbed site in June of 1987, and a distant weather database exists from that time. A set of fifteen days from this database was selected for the investigation. This set was selected so as to be representative of all storm types and obscuration conditions (i.e., mild rainshowers to severe thunderstorms) which occur within the Denver, CO, area during the June through October time frame.

Modifications were made to an off-line version of the PRF selection technique which enabled the simultaneous processing of the selected distant weather data set assuming two distinct spans of PRF values: 700–1220 Hz to match the S-Band testbed span, and 1000–2000 Hz to approximate the anticipted C-Band TDWR span. Extensive off-line obscuration assessment was then conducted on the data set, and an example of the processing which occurred for one of these days, June 12, 1987, assuming a C-Band PRF scenario follows. (This example will illustrate PRF selection for the microburst surveillance region; similar processing is conducted for the gust front region PRF selection.)

Approximately seven hours of weather data were gathered by the testbed radar on June 12, 1987. Once every five minutes over the duration of this track, the distant weather scan was conducted, and an example of the output of this scan at 2217 UT appears as Fig. 2. For this analysis, distant weather is defined to be contained within the two circles as illustrated, and further defined to be any radar sampling bin which surpasses a site dependent, season dependent threshold value (typically on the order of 7 dB SNR)*. Stapleton International Airport is located approximately 15 km to the northwest of the testbed site, and for Denver operations, the microburst surveillance region is contained within a 120-deg sector out to a range of approximately 35 km from the testbed.

The obscuration mapping function is performed on this weather data, and is seen to result in the two obscuration profiles of Figs. 3 and 4. These correspond to two priority zones which are to be protected; i.e., a zone immediately surrounding the airport runways (roughly 100 sq km in area), and a second zone which encompasses the total microburst surveillance region (roughly 1300 sq km). The selection criteria states that it is of highest priority to minimize obscuration within the airport runway zone. Subject first to this constraint, the PRF selection technique subsequently seeks to minimize obscuration over the larger area contained within the 120-deg sector.

* 7 dB SNR corresponds to a first trip reflectivity of roughly -8 dBz at the nominal airport range of 15 km.

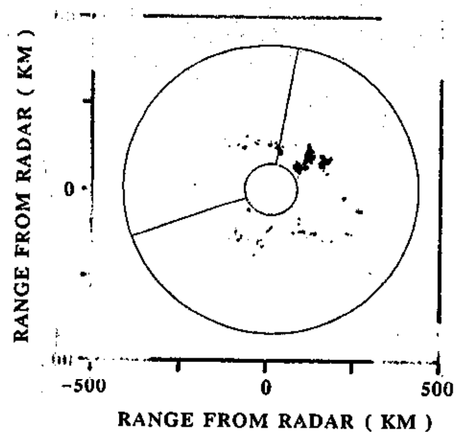

Figure 2. Distant weather on June 12, 1987, at 2217 UT. Distant weather within the 120-deg sector affects selection of PRF for microburst surveillance while all distant weather affects selection of PRF for gust front surveillance.

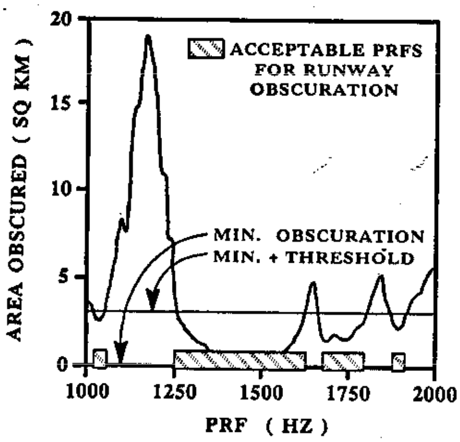

Figure 3. Obscuration assessment over airport runways on June 12, 1987, at 2217 UT. The minimum obscuration level (in sq km) is first located. A small threshold value is added to minimum level and all PRF values which result in obscuration less than the result are considered acceptable.

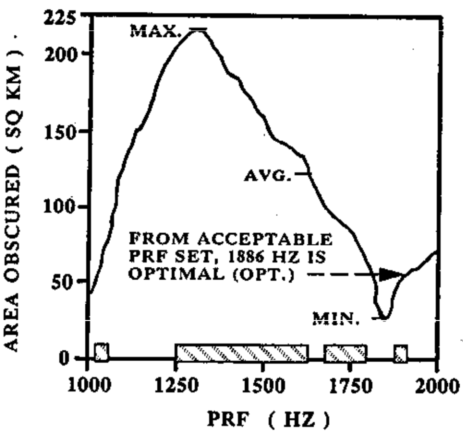

Figure 4. Obscuration assessment over 120-deg sector to a range of 35 km on June 12, 1987, at 2217 UT. From the acceptable set of PRF values (as determined in Fig. 3) that PRF which results in a minimum level of obscuration over the 120-deg sector is selected as optimal.

From each of the obscuration profiles, four values are recorded for further analysis: the maximum level of obscuration that could have resulted over the span of available PRF values, the minimum level of obscuration, the average level of obscuration, and the optimal level of obscuration. (Since the technique seeks to minimize obscuration in two separate zones using the same PRF value, the *optimal* level is not necessarily the *minimum* level.) A cumulative compilation of these four values over the duration of the track, when properly scaled, permits an assessment of the overall effectiveness of the technique for the day in question. Figure 5 provides the cumulative results of the June 12, C-Band example for the microburst surveillance region.

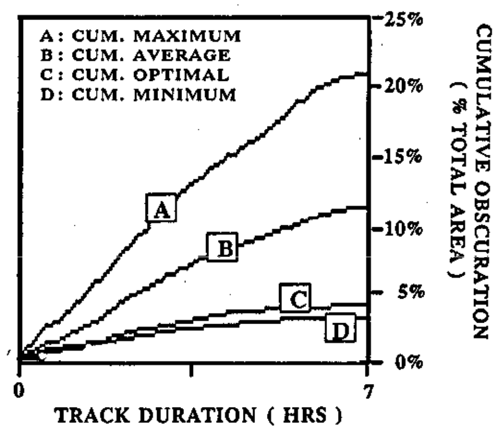

Figure 5. Cumulative assessment of obscuration conditions and PRF selection performance over microburst surveillance region (120-deg sector) for a C-Band scenario for June 12, 1987. For this example, maximum level of potential obscuration represents approximately 21% of the total area, average level represents 11%, minimum level 3% and optimal level (after PRF technique) represents 4%.

Results as derived above were obtained for each of the fifteen days of the data set and were then averaged over the data set so as to provide performance characteristics of the PRF technique over all types of obscuration conditions. Table I provides a summary of the obscuration potentials (i.e., maximum, minimum and average levels of obscuration – *Max*, *Min*, *Avg*) which can be expected assuming the two different spans of PRF values for both zones of interest. This table also provides an indication of obscuration conditions following application of the PRF selection technique (i.e., optimal – *Opt*) for these two zones. Inspection across the rows of the table indicates that the increase in potential obscuration conditions to be expected in the TDWR system over that experienced in the TDWR testbed environment is on the order of 50 to 100%.

TABLE I : INVESTIGATION RESULTS (PERCENT AREA OBSCURED)

	RUNWAYS (100 sq km)				120-deg SECTOR (1300 sq km)			
	Max	Min	Avg	Opt	Max	Min	Avg	Opt
TESTBED (S-Band)	14%	<1%	5%	1%	11%	<1%	6%	1%
TDWR (C-Band)	22%	2%	10%	3%	17%	2%	10%	5%

This analysis quantitatively establishes the importance of adaptive PRF selection as a primary method in significantly reducing the potential for obscuration within operationally significant coverage areas for both the S-band TDWR testbed and C-band TDWR systems. This reduction is observed by comparing the figures within the columns labeled *Max* and *Avg* with those within the column labeled O*pt*. A worse case scenario for the TDWR system, for example, indicates that approximately 22% of the airport runways would be obscured at any given time (on average, this obscuration would be on the order of 10%), yet with adaptive PRF selection, the expected obscuration is reduced to only 3%. (The corresponding figures for the testbed radar are seen to be 14%, 5% and 1%, respectively.)

The above analysis provides a mechanism by which one can surmize that roughly 3% of the airport runways are expected to be obscured following adaptive PRF selection during TDWR microburst surveillance operations. This figure represents an *average* statistic, averaged first over individual track duration and second over the selected data set. The distribution about that average figure is also of interest and appears in Fig. 6. Here one sees various levels of obscuration conditions which are expected to exist following application of the PRF technique. This information is distributed over the total track time of all fifteen days of the data set for both testbed and TDWR system and for both zones of interest. (The final impact of these levels of obscuration on data quality considerations depends, once again, on the relative comparison of the in-trip and out-of-trip signal strengths.) Clearly, adaptive PRF selection can minimize, but not totally eliminate range obscuration.

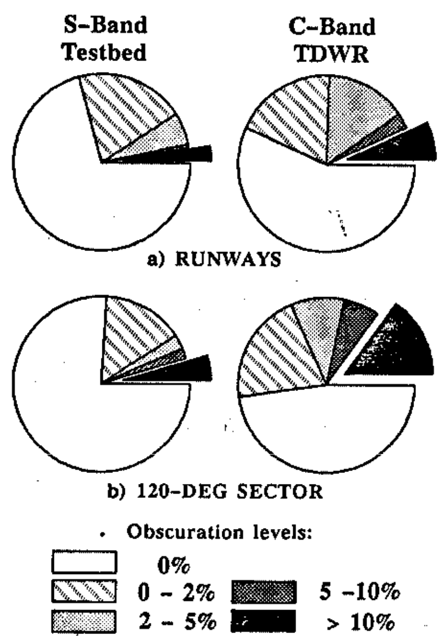

Figure 6. Time distribution over which various obscuration conditions are expected to occur following adaptive PRF selection for testbed and TDWR system. a) Highest priority airport runway zone. b) 2nd priority 120-deg sector.

5. FUTURE EFFORTS

While adaptive PRF selection is felt to be an excellent first step in the range obscuration mitigation effort, additional mitigation techniques are being investigated for possible use within the TDWR system. An enhancement to the PRF selection technique itself is being considered whereby multiple PRF values would be used within a surveillance sector. Instead of selecting a single PRF value for use within the 120-deg microburst surveillance sector, for example, the sector would be partitioned into smaller segments (eg., four 30-deg segments) and the PRF used within individual segments would be selected based solely on distant weather conditions within the segment.

A promising technique to augment adaptive PRF selection is radar phase modulation [5,6]. By modulating the phase of the outgoing pulse, and compensating* for the modulation only for signals returning within the unambiguous range interval, the error due to out-of-trip contributions within the radial velocity field can be significantly reduced. Depending upon the modulation strategy and the relative strengths and velocities of the in-trip and out-of-trip signals, valid in-trip velocity estimates may be achieved even in the presence of significant contamination (eg., out-of-trip signal levels comparable to those of the in-trip). This mitigation technique is expected to be used in conjunction with adaptive PRF selection and is currently an area of active research and experimentation within the TDWR testbed.

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* By phase modulating the coherent local oscillator (COHO), compensation is achieved automatically on received signal, and hence requires no change to the system digital signal processor.