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N-Pulse Logic Peak Detection for Laser Radar Range Measurement of Distributed Range Targets

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FOR THE COMMANDER

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N-PULSE LOGIC PEAK DETECTION FOR LASER RADAR RANGE MEASUREMENT OF DISTRIBUTED RANGE TARGETS

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ABSTRACT

In this report N-pulse peak detection logic is discussed in the context of high angular resolution laser radar range processing. In the event that a resolved target is obscured by one or more unresolved scatterers such as wires, tree branches, camouflage netting, antennas, and the like, one sees multiple returns in the range I.F. due to the multiple scatterers in the line-of-sight path to the target. A laser radar that peak detects the N largest pulses in the range I.F. utilizes N-pulse peak detection logic.

This report contains a discussion of the utility of N-pulse logic and also samples of data of N-pulse returns from trees and wires. A limit is found for the average resolvable distance between two scatterers based on Gaussian pulse shapes but not taking into account noise and target fluctuations (speckle).

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1.0 INTRODUCTION

CO_2 laser radars provide high angular resolution as well as high range precision. For example, the MIT/LL experimental test bed laser radar[1,2] presently has an angular resolution of 33 μrad with an unambiguous range precision of 75 cm. This laser radar is described below.

For target ranges on the order of a few kilometers, this high angular resolution translates to a rather small spot on the target. At 3 km the Gaussian spot full width half maximum (FWHM) is 10 cm. This small cross-range spot is given as the justification for the assumption that laser radars are free of subpixel clutter. Subpixel clutter comes from unresolved scatterers in the transmit beam.

In a cluttered tactical target environment many scenarios exist where the assumption of the lack of subpixel clutter does not hold. For example it has long been known that laser radars serve well as wire detectors.[3] A wire presents an essentially one-dimensional scattering profile. In the event that the wire is in front of a range resolved extended target, the radar will see two returns: one from the target, and one from the wire. Other examples of range resolved targets that give rise to multiple returns include girder structures (bridges and buildings), antennas, gun barrels, tree branches, and camouflage netting. In each case laser radar range data exist that illustrate the existence of multiple pulse returns.[4] Several examples are illustrated in this report.

Such distributed range targets can be characterized by the nature of the radar pulse returns. Either the multiple scatterers are well resolved in range which gives rise to a set of discrete pulses, or the scatterers are not range resolved, which results in pulse stretching caused by the overlap of the separate scatterers' returns. Tree branches are examples of targets that give rise to pulse stretching. Examination of pulse returns may thus yield information about the target that may well be termed target texture, defined on a scale of pulse width and spot size (for cross range). For hard targets the return pulse shape is identical to the transmitted pulse shape.

The MIT/LL laser radars are built with peak detection (record largest peak within range window) logic which can provide significant improvement over first pulse logic in terms of probability of anomaly to probability of false alarm as a function of the CNR.[5,6] Logic that finds the first N largest pulses in the return is called N-pulse logic.

This report examines some of the issues of the utility of N-pulse logic in extracting partially obscured targets. In the following the testbed laser radar is described as well as N-pulse logic. In Section 2 a discussion of pulse stretching from textured targets is given. Section 3 contains a presentation of sampling of range profiles from a variety of hard and textured targets. From these results conclusions are drawn on the upper bounds of N in the sense of accounting for the meaningful information in the range profile from distributed scatterers. In addition to N-pulse logic a short discussion is also given on using additional logic which could adapt to the variety of target returns to give estimates of target texture and obscuration. Such processing could also use nearest neighbor pixel values, such as is currently done in cluster averaging, to enhance target detection.

1.1 High Angular Resolution Laser Radar

The CO_2 Laser Radar used to investigate pulse returns from textured targets is the MIT/LL large aperture test bed radar. This radar is described in the FCT series project reports.[1] The present configuration of the heterodyne detection CO_2 laser radar includes a 39 cm aperture yielding 33 μrad angular resolution. The pulse laser is a 1 W average power, cavity dumped or Q-switched CO_2 waveguide laser pulsed at 20 kHz for a range ambiguity of about 7.5 km. The nominal cavity dumped pulse width, FWHM, is about 35 ns measured directly with a square law detector (power). In heterodyne detection the FWHM of the same pulse is about 1.5 times broader since the field envelope is detected linearly. (For a Gaussian pulse shape the FWHMs for power and field are related by $\sqrt{2}$.)

1.2 N-Pulse Logic

N-pulse logic is an extension of peak detection logic which consists of a comparator and a sample-and-hold buffer (latch). In peak detection the signal is sampled and digitized, and the current digitized level is compared to the level held in the sample-and-hold buffer. If the new level is greater than or equal to the stored level, the new level is placed in the sample-and-hold along with the time (i.e., range) when it occurs. Thus the peak level within the sampled range window is found. For N-pulse logic N comparators and sample-and-hold buffers are used with the necessary logic to record the N largest peaks that occur. Information on pulse spreading is lost with peak detection. Therefore additional logic is necessary for pulse shape measurements. The alternative to additional logic is to store all the sampled points in the range return which would require considerable memory. An indication of the trade-off between preprocessing and data storage can be had from current tactical laser radar requirements. Tactical laser radar pulse rates are typically bounded by 10 kHz to 100 kHz. One meter range precision requires a digitization rate of at least 150 MHz. The minimum recording bandwidth corresponding to storing every 8-bit sample in a 300 m range window is (300 samples x 8 bits x PRF) 24 MHz to 240 MHz.

2.0 RESOLVABLE DISTANCE OF DISTRIBUTED SCATTERERS

The actual range resolution of a laser radar is a function of the pulse width, SNR, and digitization rate. In the usual mode of operation of the laser radar, the digitization rate provides a range bin which is narrower than the pulse width. For example a typical pulse width is about 35 ns FWHM (power) or 11 m in free space propagation, whereas the range bin is 75 cm (200 MHz digitizer) for the MIT/LL testbed laser radar. Thus the peak detection electronics resolve the pulse shape. The data in this report were taken with the laser running in a Q-switched mode resulting in a somewhat longer pulse width which is approximately Gaussian. The cavity dumped pulse shape is complicated in that it is a mixture of the cavity dumped spike on top of the base Q-switched pulse.

If the pulse is scattered from range unresolved scatterers, the range profile will include a superposition of the various returns. If the scatterers are separated in range over a much larger distance than the pulse width, discrete pulses are observed in the range profile. As the discrete scatterers move closer together the superposition of the scattered pulses overlap. At some point the sum of the scattered pulses appears as a single pulse with one peak. This effect can be modeled. In the following the pulse shape is assumed to be Gaussian, and noise processes are neglected.

Consider two scatterers, one unresolved in front of another. Assume that the range profile consists of the sum of the two scattered pulses (assumed to be Gaussian) with a delay corresponding to the range differential. Also assume that the scattered amplitude of the first pulse is set equal to one, and the amplitude of the second is allowed to vary from 0 to 1. Because of symmetry in the results this accounts for all possible normalized returns.

If the delay is small compared to the pulse width, the resulting pulse shape will appear to be broadened out and would not necessarily exhibit two peaks detectable with the peak detector. More generally, the pulse shape, W, is a function of: Δx, second scatterer separation, a relative second scatterer intensity, $0 \leq s \leq 1$, and range R. The form chosen for $W(\Delta x, s; R)$ is the sum of two, unity standard deviation Gaussian pulses separated by Δx: the first having unit amplitude with the second having an amplitude of s. Figure 2.1 is a plot from which one can find the minimum distance between two scatterers and still be able to detect two pulses in the return by the following criterion. If the first derivative of $W(\Delta x, s; R)$ with respect to R had three zeros, then the two peaks were judged resolvable. This gives a lower bound on the resolvable range separation. The results of Figure 2.1 are still valid if the first scatterer amplitude is normalized to the second since the result is symmetrical in s. From Figure 2.1 one may conclude that in order to discriminate two pulses in 2-peak detection, the second scatterer must be separated by more than 2 sigma from the first scatterer, when the two pulses have equal return strengths.

The implications of Figure 2.1 may be applied to trees. Assume a tree canopy to be a distributed scatterer. It is likely that none of the branches are more than 2 sigma apart for a 35 ns pulse (power). Therefore the returns from the branches look like a stretched pulse with one peak. However the canopy height (determined by the lowest branches) may be separated by 2 sigma from the ground in which case a second pulse from the ground may be detectable. Also, in the case of camouflage netting, the net would need to be separated by 2 sigma from the target since the netting has a reflectivity comparable to that of military vehicles.'

These observations do not include the details of target return fluctuations such as speckle which a detailed probability of detection model would have to include.

3.0 AEROSOL MODE RANGE DATA

This section contains a number of range profile data sets presented as figures. Range profiles are generated by sampling the entire range gate during the ranging pulses return with a fast A/D converter. For example, an A/D running at 100 MHz corresponds to range sampling in 1.5 m increments. This mode of data recording is referred to as the aerosol mode. The following paragraph contains information common to all the Section 3 figures.

Range profile data were taken with the radar's scanners disabled (stare mode). The range returns are heterodyne detected followed by a linear envelope detector. The envelope amplitude is proportional to the detected field strength envelope and is digitized by an Analogic Data 6000 digital scope running at 100 MHz. The digitized data are stored internally and transferred to a floppy disk. The data presented below are either single pulse returns or pulse averages of 64 consecutive range profile returns taken at a pulse rate of 18.6 kHz. Each case is noted explicitly. The range offset to the targets is typically about 2.6 km. The radar is looking out at the targets (buildings and trees) within a few degrees of normal incidence. The sample rate is 10 ns/point (100 MHz). In cases where the range axis has been expanded, sampled data points have been labeled explicitly with stars.

Several exemplar data sets of range profiles including extended targets (e.g., walls), unresolved targets in front of extended targets, distributed targets (deciduous trees with no leaves), are included in this section. These examples, considered in turn below, suggest additional processing to extract the desired range return in the presence of subpixel clutter.

3.1 Hard Target/Pulse Shape

Figure 3.1(a) is a range profile from a return off a flat wall. The expected return for this target is a pulse shape profile of the transmitted pulse. Figure 3.1(b) is an expanded view of Figure 3.1(a) from which the linearly detected FWHM may be measured. These data were taken with the laser operating in a Q-switched mode instead of the cavity dumped mode resulting in a longer pulse width. The approximate Gaussian pulse profile can be seen in this figure.

3.2 Resolved Distributed Scatterers

Figure 3.2(a) is of a wire in front of a building (wall). On the average the wire is almost as bright as the wall. One may observe wire returns in peak detected laser radar range imagery and find that typically the wire return is selected about half the time over wall returns.

Figure 3.2(b) is from the leading edge of an aircraft wing in front of a hangar door. The two returns are overlapped, but two peaks are still resolvable.

3.3 Tree Profile Data

Figures 3.3(a-f) are of deciduous tree returns (no leaves). This set of figures is from single return data (no averaging). The principal effects of pulse stretching, and multiple peaks can be seen throughout. As a final example of pulse stretching in trees, Figure 3.3(g) is a frame averaged tree return. This blowup shows that the FWHM is about 210 ns.

4.0 CONCLUSION

In this report N-pulse logic has been defined. N-pulse logic has been looked at as a possible enhancement to laser radar foliage and camouflage penetration. The tree data shown in Section 3.3 demonstrate that tree penetration is possible to significant depth (30 m for example). One should be reminded that these tree data are taken at near normal incidence, that is looking into the trees, not down from above. Looking down on trees from above one would expect tree penetration to decrease since trees are assumed to grow in such a way as to maximize cross section from above to absorb sunlight, and minimize cross section from the side to decrease wind resistance.

The ability to see 30 m into tree clutter from the side is significant. The effect of leaves will undoubtedly reduce this penetration. An examination of the sample tree returns in Figure 3.3 reveal that there may be a number of peaks. However, the three largest peaks seem to account for the bulk of the resolvable returns.

In addition to looking for the peaks, as in N-pulse logic, one may also consider a processor that is sensitive to pulse stretching from distributed scatterers. Assuming that targets of interest give hard returns and stretched pulses come from clutter, one should be able to increase detection probability. Such a processor would make a decision on pulse width as well as the peak level and select the pulse having the narrowest width with largest return.

In the case of targets concealed by camouflage netting 2-pulse logic shows possibilities in target detection. Penetration of camouflage netting by radiation from an active sensor will be reported on elsewhere.[7] In addition, 2-pulse logic would enhance target detection in the event that wires, antennas, gun barrels, and the like, which are unresolved, are used as cues in target detection/identification.

REFERENCES

1. Lincoln Laboratory, MIT Project Report series FCT (numbers 1 through 5) contain explicit descriptions and design details of the MIT/LL large aperture testbed laser radar built for the Fire Control Advance Technology (FCTA) program.

2. D.U. Fluckiger, M.P. Bolduc and L.A. Prior, "Large Aperture Multi-dimensional Laser Radar Testbed," Project Report FCT-5, Lincoln Laboratory, MIT (11 March 1988).

3. R.L DelBoca and R.J. Mongeon, "Multifunction CO_2 Heterodyning Laser Radar for Low Level Tactical Operations." IEEE Proc. Nat. Aerospace and Electronics Conf. Vol. 3, pp. 1079-1088 (1979).

4. Lincoln Laboratory, MIT has collected extensive laser radar range and Doppler data of military targets with the transportable laser radar. This laser radar has a 200 μrad IFOV, and range digitization corresponding to 6 m range resolution. The radar is operated in a framing mode in which the target may be optimally/over/under sampled in azimuth and elevation.

5. J.H. Shapiro, private communication.

6. J.H. Shapiro, R.W. Reinhold and D. Park, "Performance Analyses for Peak-detecting Laser Radars," Laser Radar Technology and Applications, Proc. SPIE, Vol. 663 (1986).

7. D.U. Fluckiger, "IR Measurements of Lincoln Test Target and Camouflage Netting," Lincoln Laboratory, MIT Technical Report (to be published).

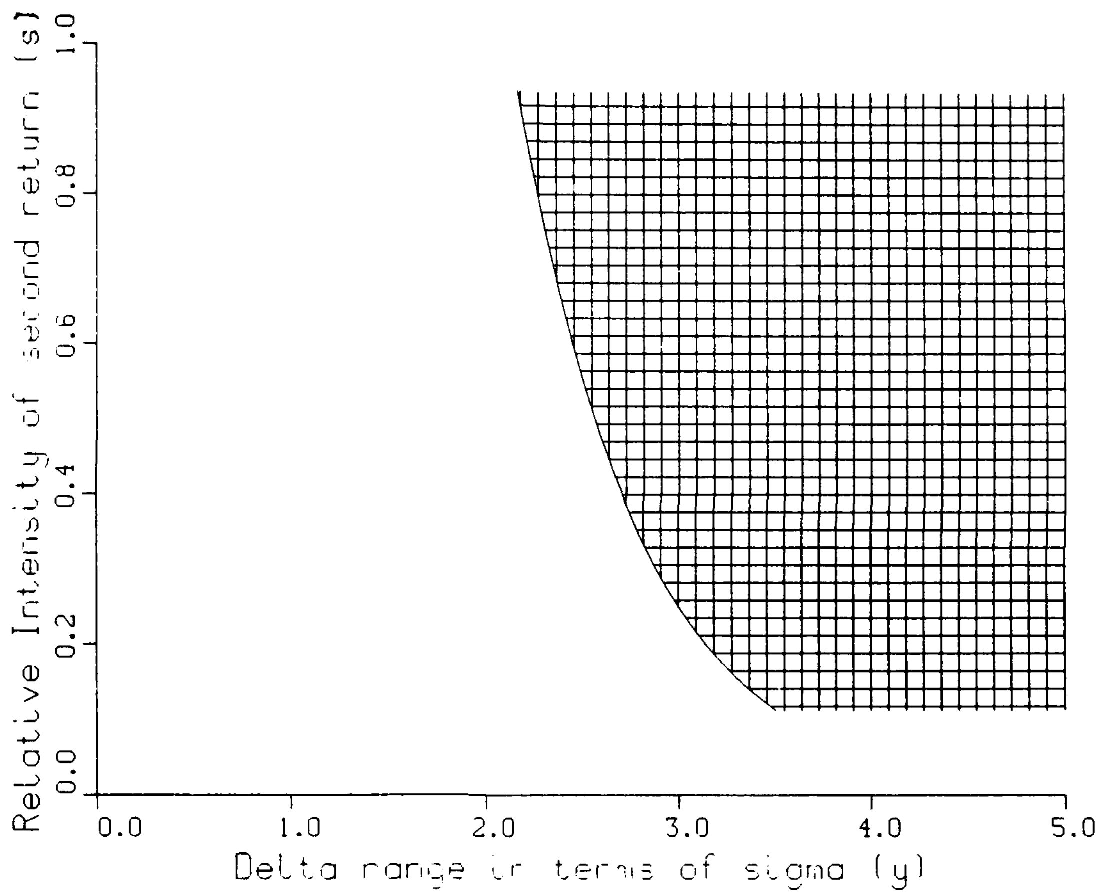

Figure 2.1. Range resolvability of two pulse returns as a function of target separation and relative target scattering amplitude.

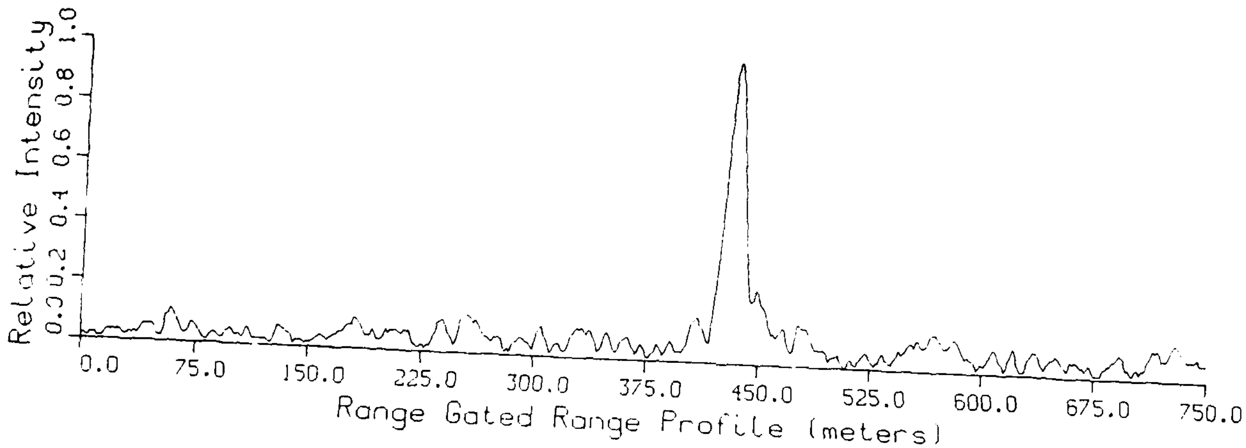

Figure 3.1(a). Range return profile from a hard wall with no averaging.

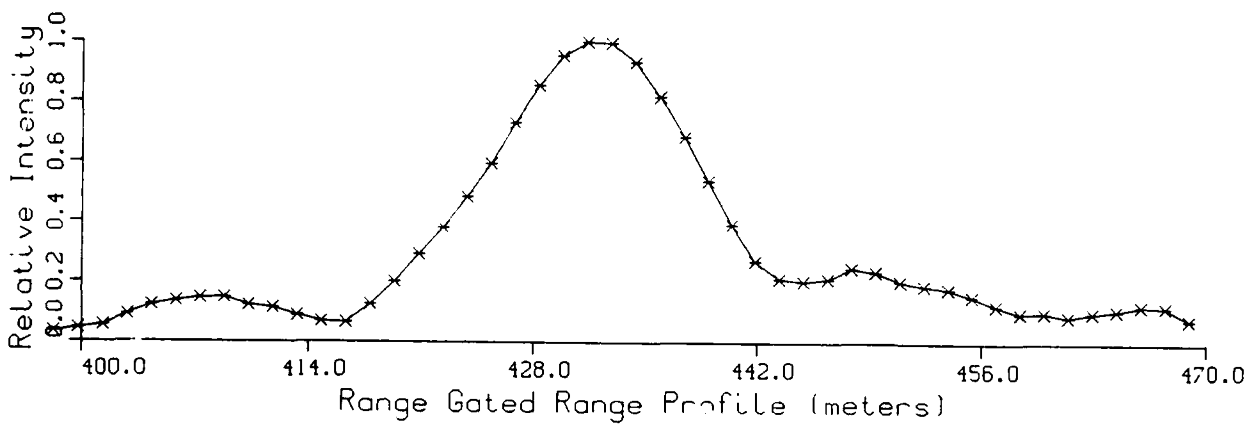

Figure 3.1(b). Enlargement of 3.1(a) range profile around pulse: FWHM is 90 ns.

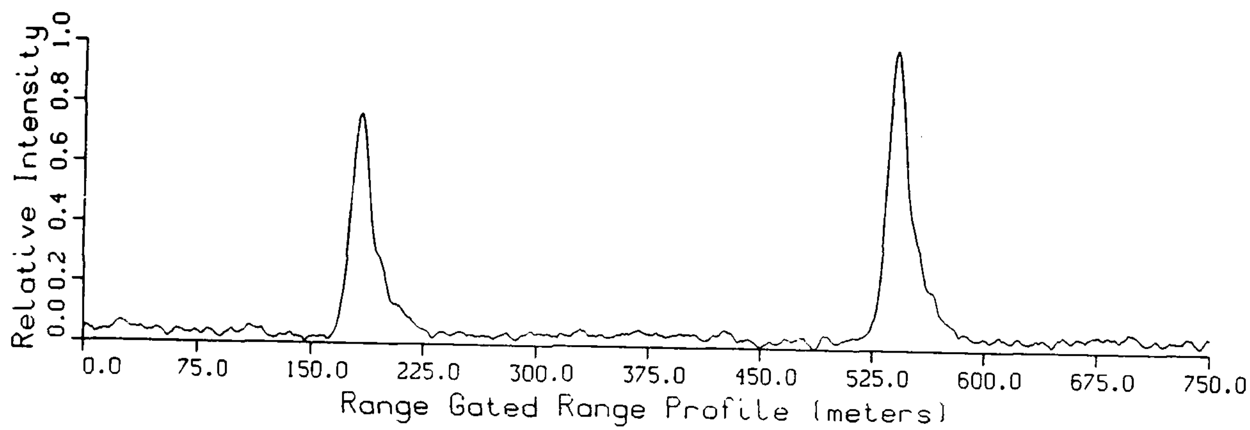

Figure 3.2(a). Simultaneous wire and wall returns, 64 frame average.

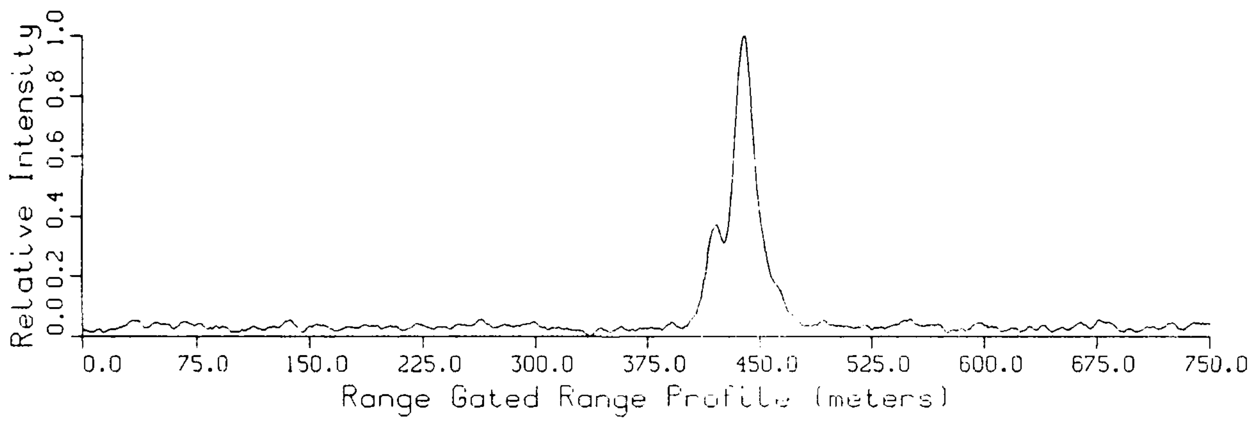

Figure 3.2(b). Range profile of an aircraft wing (leading edge) in front of a wall, 64 frame average. The two returns are resolved in range.

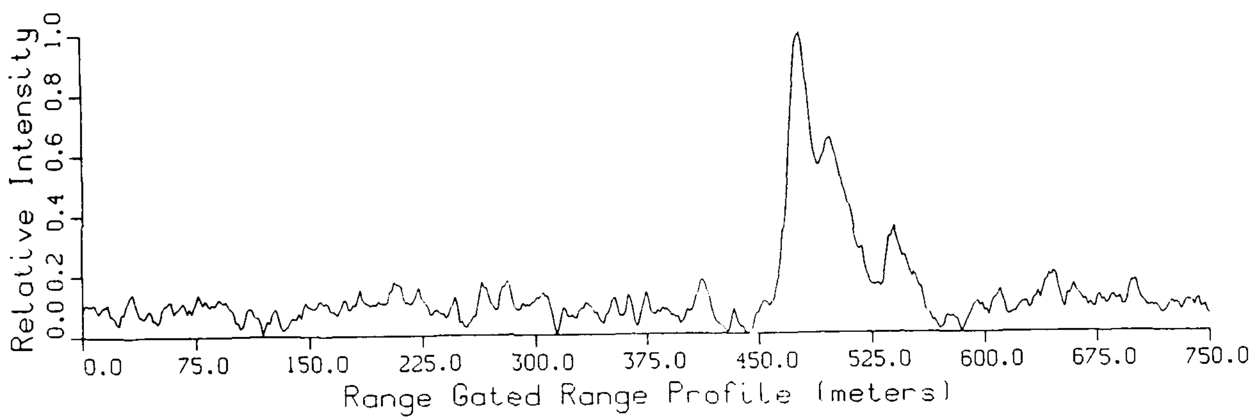

Figure 3.3(a). Range (unaveraged) profiles of deciduous tree returns viewed at near normal incidence, from the side. Data were taken when no leaves were on the trees.

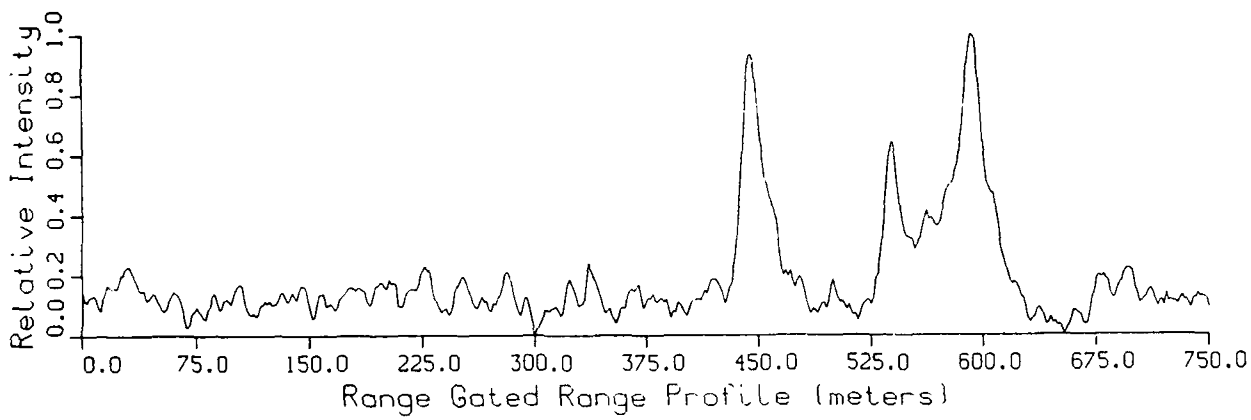

Figure 3.3(b). Range (unaveraged) profiles of deciduous tree returns viewed at near normal incidence, from the side. Data were taken when no leaves were on the trees.

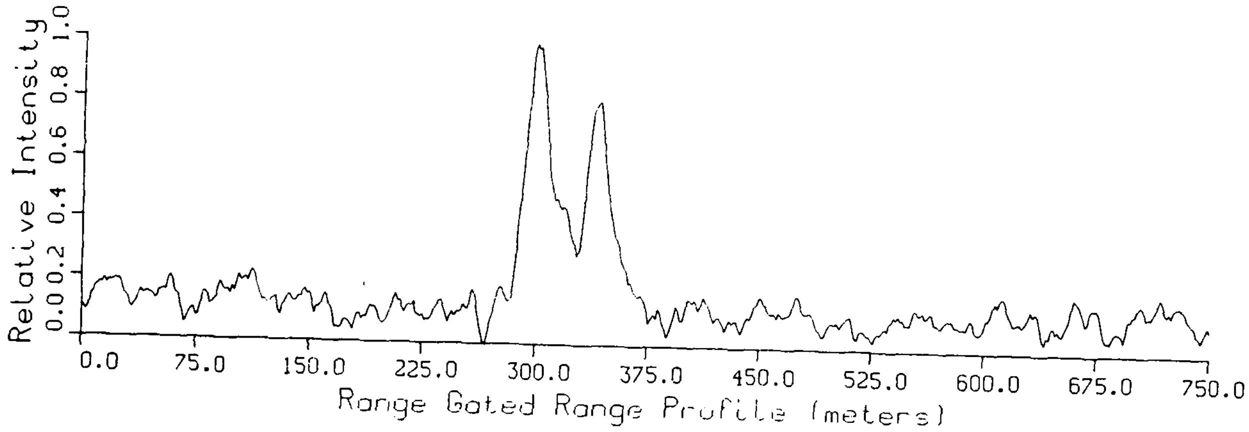

Figure 3.3(c). Range (unaveraged) profiles of deciduous tree returns viewed at near normal incidence, from the side. Data were taken when no leaves were on the trees.

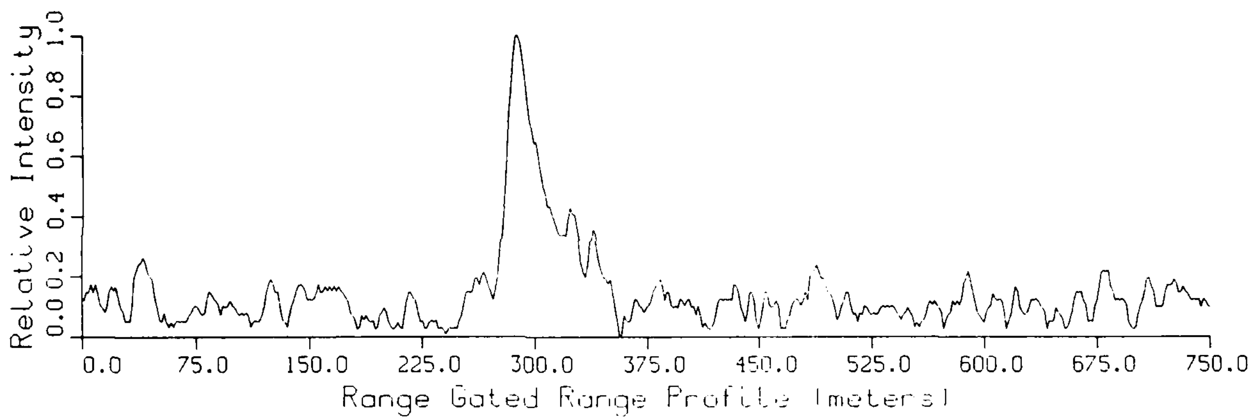

Figure 3.3(d). Range (unaveraged) profiles of deciduous tree returns viewed at near normal incidence, from the side. Data were taken when no leaves were on the trees.

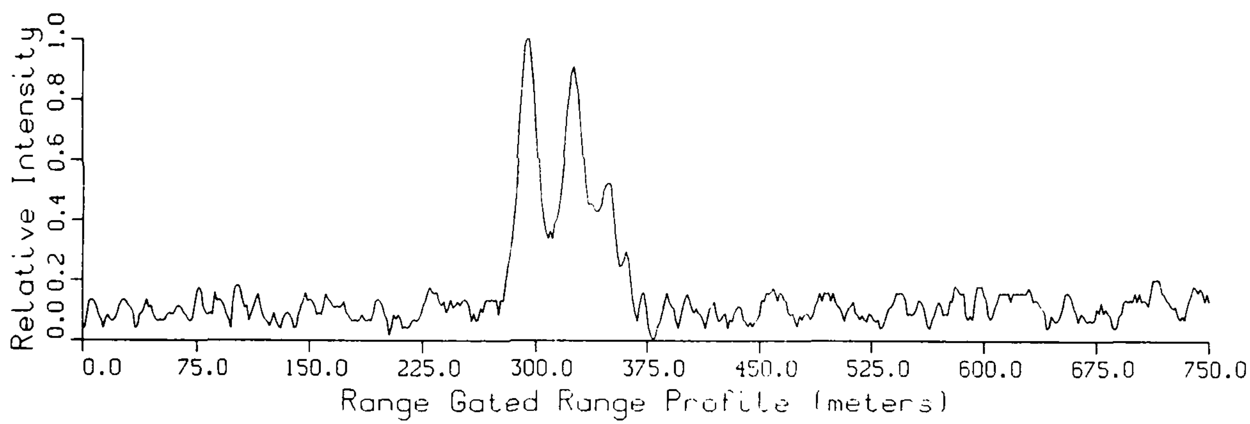

Figure 3.3(e). Range (unaveraged) profiles of deciduous tree returns viewed at near normal incidence, from the side. Data were taken when no leaves were on the trees.

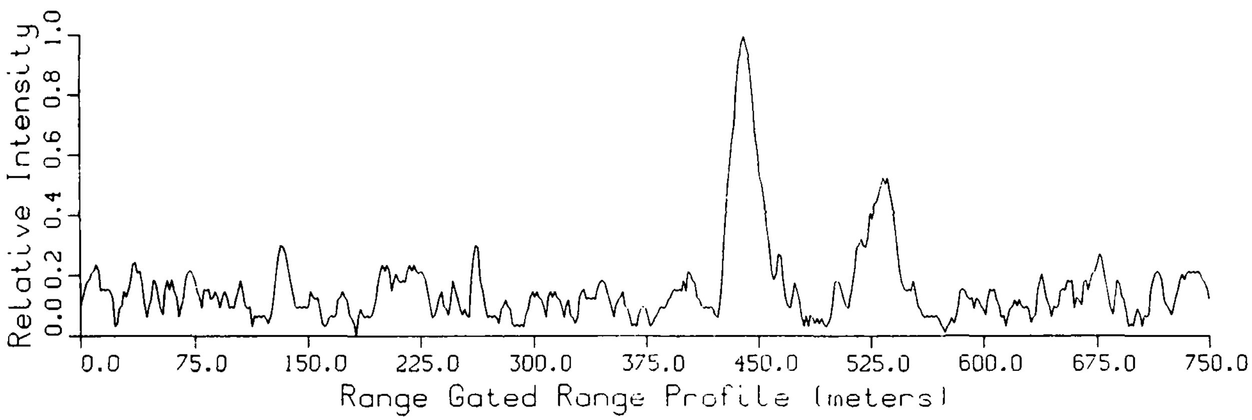

Figure 3.3(f). Range (unaveraged) profiles of deciduous tree returns viewed at near normal incidence, from the side. Data were taken when no leaves were on the trees.

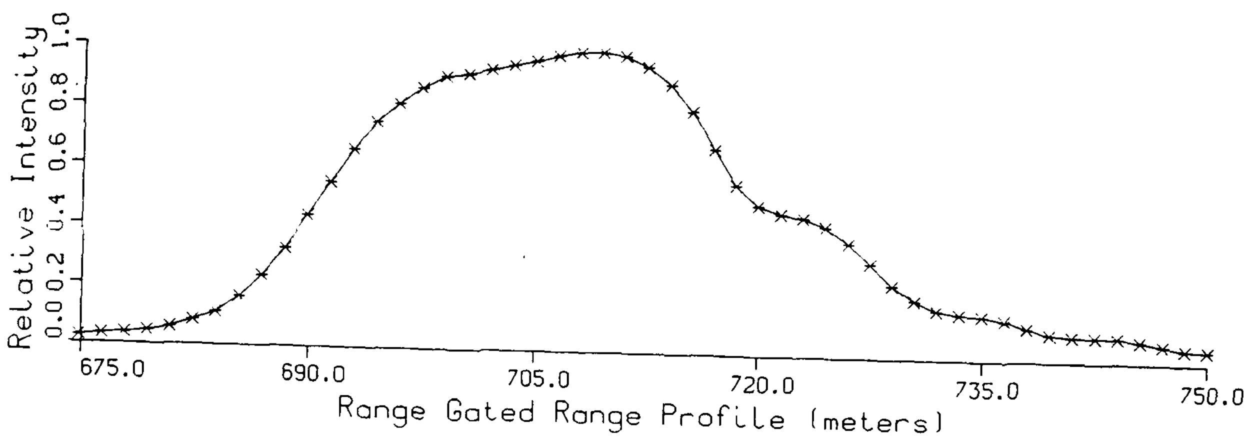

Figure 3.3(g). Expanded range profile (averaged) from trees; the pulse is stretched by a factor of 3.

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In this report N-pulse peak detection logic is discussed in the context of high angular resolution laser radar range processing. In the event that a resolved target is obscured by one or more unresolved scatterers such as wires, tree branches, camouflage netting, antennas, and the like, one sees multiple returns in the range I.F. due to the multiple scatterers in the line-of-sight path to the target. A laser radar that peak detects the N largest pulses in the range I.F. utilizes N-pulse peak detection logic.

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