28PD3 Prototype Development of a Pseudo-Random Modulation Range Imager

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The results from the development of a breadboard prototype high resolution, small, robust pseudo-random modulation (PRM) cw laser radar are presented. The addition of the novel concept of digital Resolution Enhancement Technique provides a substantial improvement in PRM resolution capability. Fully realized, the range imager concept will measure the range to long distance targets with high sensitivity and resolution, and also provide information on precise target direction, due to the small divergence of the solid state laser transmitter. Combining multi-beam range data and angle information, a precise and complete range image can be generated in real-time. The topographic maps generated by the range imager will be of immense value in detecting any minute changes that occur in the viewed objects. There are many other applications of such a capability, including automated rendezvous and docking in space, remote manipulation of spaceborne systems, and remote inspection of facilities in isolated locations. Issues addressed by system development of the PRM laser radar are three-dimensional target position measurement, agile access over an extended field of regard, and high resolution of range and image of objects in varying degrees of ambient light.

Range sensing techniques can be grouped into two categories: passive and active. The real-time application of passive techniques is limited in resolution and speed due to the complexity of the data processing algorithms and extended processing time [Ito, 1990]. The conventional active (cw) imager systems [Herbert and Kanade, 1986] are limited by their high complexity and cost. Pulsed laser radar systems have been utilized in range measurements, with limited range resolution which is essentially governed by the laser pulsewidth. In addition, conventional pulsed laser radar systems are limited in their applicability due to their complexity, large size, and high cost. Another common technique is frequency chirping and coherent range detection, which is, however, limited in range and resolution (< few thousandths of the range coverage) due to the limited range of frequency chirping and laser mode bandwidth. These techniques rely on analog signal processing which requires a large return signal; noise bandwidth is very wide in these techniques, unlike that of the PRM cw lidar technique.

To overcome the difficulties encountered in conventional laser radars and to develop a maintenance-free, operational system for mission oriented applications such as remote range imaging in a spaceborne environment, SESI has developed the novel concept of the PRM cw laser range imager system which utilizes a commercially available diode laser, or novel hybrid MOPA LiSAF laser, and a focal plane detector array combined with an agile beam scanning subsystem. With this sensor, the range and reflectivity of the target are simultaneously measured by combining SESI's proprietary Range Enhancement Technique [Lee, 1992] and the PRM technique.

The PRM cw lidar relies on the delta function property of the autocorrelation function in a pseudo-random (PR) code. The transmitter continuously sends a nth order PR code modulated signal, while the received signal is averaged for M cycles of the PRM sequence. Cross-correlations of the averaged signal with the transmitter modulation code for each of n time bin shifts will equal zero, except in the case where a null phase difference between transmitted code and received signal is realized. The resolution enhancement technique smears the correlation peak over adjacent range bins, which allows for range resolution several orders of magnitude greater than that conventionally obtained from the transmitted code modulation frequency.

We have performed a feasibility study of the PRM ranging sensor utilizing the Range Enhancement Technique which includes a laboratory experiment, intermediate range measurements, long range simulation studies, distributed target measurement and a preliminary experiment for Doppler measurement requirements. A breadboard ranging sensor was built, consisting of an 8 mW AlGaAs diode laser transmitter modulated at up to 20 MHz; a 20 cm Schmidt-Cassegrain telescope, relay and focusing optics, color filter and SiAPD detector receiver; I/O control card and PC internal transient digitizer of 20 MHz, 8 bit resolution; and PRM electronics. Figure 1 is a photograph of the breadboard system, including a full-sized PC, which fits on a 61 cm x 121 cm sized optical breadboard. The range Resolution Enhancement Technique was tested by a simple setup in the laboratory using the breadboard system and a target board at various distances. The high resolution timing information was encoded to the PRM code through a 1 nsec resolution time delay generator. The lidar signal was then continuously integrated as the delay was varied from 0 to 150 nsec. The integrated signal was correlated with the reference code to generate the correlation coefficients showing significant values for two or three adjacent range bins. The distance is obtained by a correlation score-weighted average of the modulation bin positions. The measurements were performed for a range of 0 to 30 m, where the accurate ranges to the target were measured to within 1 cm by a tape measure. Figure 2 shows the resulting range measured values plotted against the tape measured values. The average deviation of the range measured values is 21 cm, while the expected resolution of a conventional system with a 10 MHz modulation frequency is 15 m. The Resolution Enhancement Technique gives a nearly 2 orders of magnitude increase in the resolution obtained. We believe that it is possible to substantially increase the capability of the PRM system using more advanced electronic design techniques. We are currently designing a PRM system capable of up to 50 psec time resolution, resulting in a 7.5 mm range resolution.

A simulation of a long range measurement in combination with the results presented here form the basis of continued work at SESI for the development of a large distance range imager. The simulation parameters are listed in Table I, which indicated detection of targets at up to 60 km distance with 125 msec integration time (see Figure 3.) The transmitter combines a semiconductor laser master oscillator and solid state power amplifier in a hybrid MOPA laser. The MOPA laser has the advantages of the direct modulation capability of the semiconductor laser and the high gain and low output divergence of the solid state laser amplifier.

Ito, T., L. S. Davis, "Fast range scanner using an optic RAM," Proc. of IEEE Int. Conf. on Robotics and Aut., 1503-1508, 1990.

Herbert, M., and T. Kanade, "Outdoor scene analysis using range data," Proc. IEEE International Conf. on Robotics and Aut., 1986.

Lee, H. S., and R. Raviswami, "Study of pseudo noise diode laser for ranging applications," SPIE Vol. 1829, Cooperative Intelligent Robotics in Space III, p. 36, 1992.

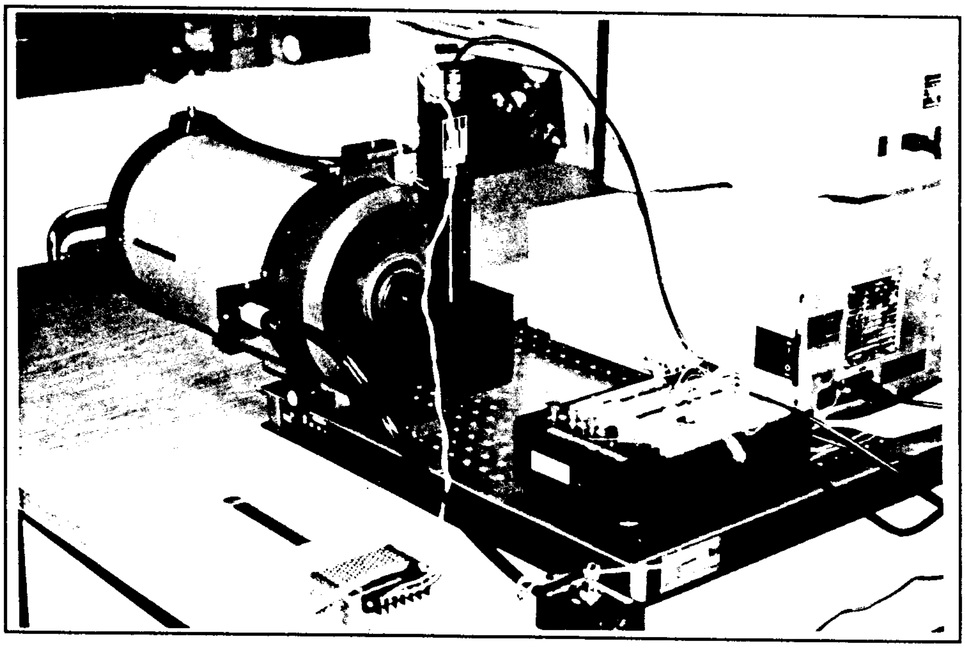

Figure 1. Photograph of the Phase I breadboard PRM lidar system.

Laser Transmitter	
AlGaAs Diode Laser	200 mW
LiSAF MOPA	5 W
Wavelength	780 nm
Beam Divergence	0.1 mrad
Receiver	
Aperture	20 cm dia.
FOV	0.1 mrad
Target (Large Area)	
Reflectivity	0.2
Detector (SiAPD)	
Quantum Efficiency	0.8
Avalanche Gain	100
Excess Noise	.02M+.98(2-1/M) for M = ~200
Dark Current	15 nA
Modulation Frequency	10 MHz

Table I. Representative system parameters used in the simulation

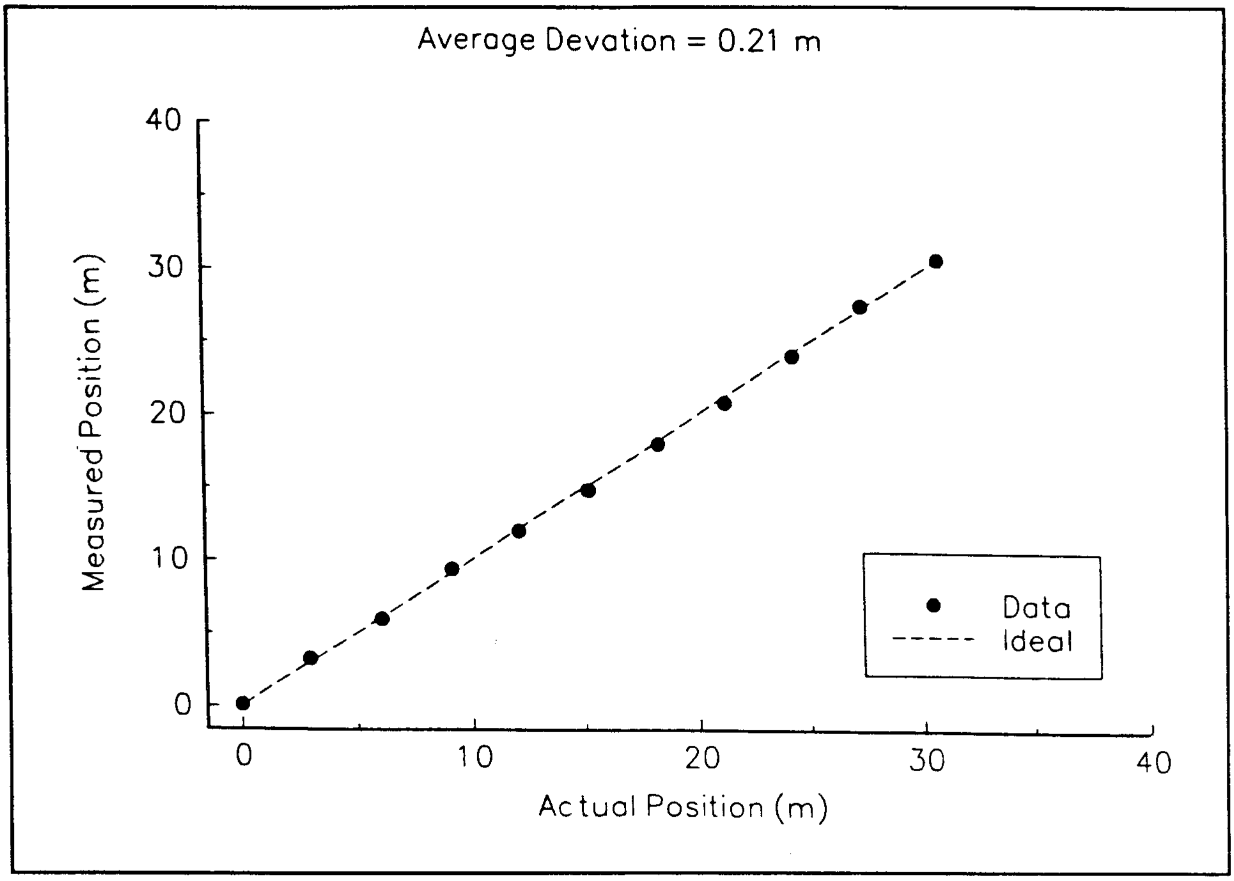

Figure 2. Range measured by the PRM/RET vs. actual distance; one hundred fold improvement over the resolution of the conventional PRM technique is demonstrated.

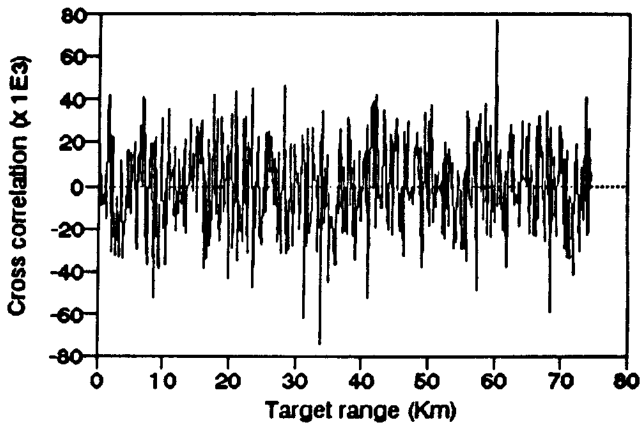

Figure 3. Computer simulated long range (60km) target signal with 125 msec integration.