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APPLICATIONS OF A GATED IMAGING SYSTEM IN EVALUATION OF LASER D--ETC(U)
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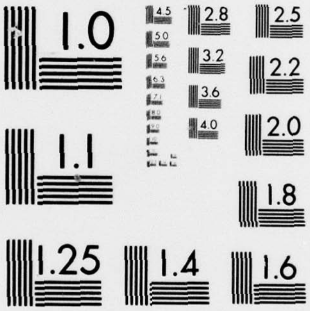

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APPLICATIONS OF A GATED IMAGING SYSTEM IN EVALUATION OF LASER DESIGNATOR PERFORMANCE

⑪ JUN 1978

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In the early 1970's the Army Materiel Test and Evaluation Directorate, White Sands Missile Range, undertook a multi-year test methodology development program to perfect techniques and develop hardware required to evaluate an anticipated family of Army Laser Designators. Standard laboratory test instruments and procedures were readily available; however, the more complex problems of energy distribution within the laser beam were not resolved. A concurrent development, at this point, was a shift toward acquiring data, wherever possible, in an image format, and subsequently processing the data on a large-scale digital computer. These two ideas led to the development and subsequent procurement of a data acquisition system known as the Laser Spot Scanning System or LS^3.

The LS^3 is a gated, image-intensified silicon vidicon camera with a standard S-1 response. The camera is equipped with a 1.06 micron spike filter mounted on a 15 mm to 150 mm zoom lens. Mounted on top of the camera's environmental container is a YAG 444 series photo-diode with associated optics. The photo-diode controls the gating function of the camera. Control of the camera is remoted, and the output recorded on a standard video tape recorder and/or displayed on a standard closed circuit television monitor. (See Fig. 1, for LS^3 configuration).

The LS^3 is operated in one of two modes. The gated mode is used to provide the greatest system dynamic range, and is required for collecting energy mapping data. In this mode, the photo-diode senses the first two laser energy returns from a device under test, sets a time interval, and gates the image intensifier high voltage on at the time of the next anticipated pulse. The next pulse, and following pulses, must arrive within +8, -2 microseconds of the

040 100

78 06 09 085

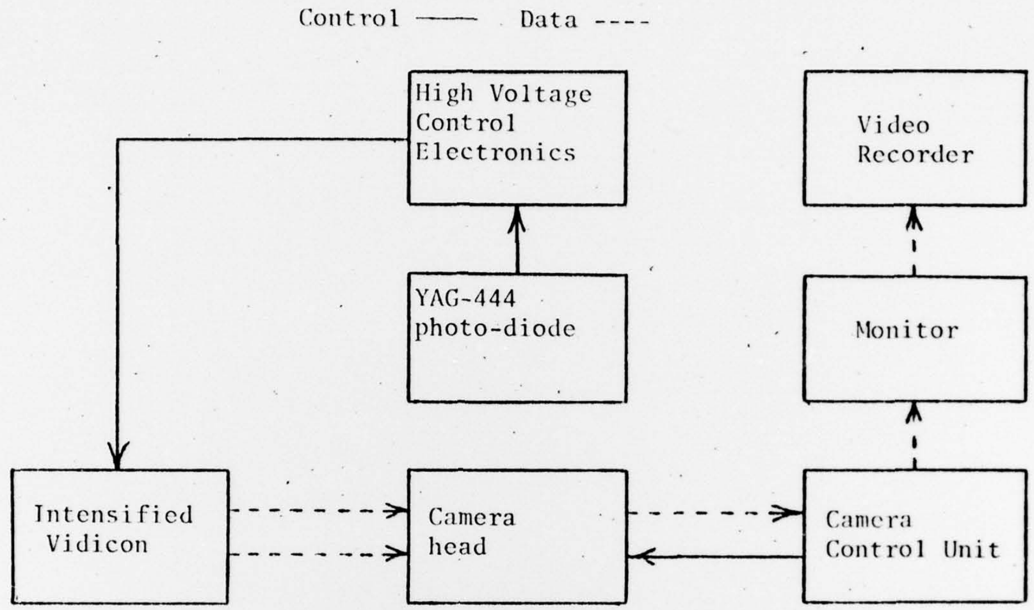

Figure 1 LS^3 Configuration

computed time to retain lock. If the incoming pulse is outside the time limits, two more pulses are required to reset the gating network. Maximum sensitivity of the camera in this mode is 1×10^{-9} w/cm^2; the instantaneous dynamic range of the unit is 48:1 in terms of irradiance at the input aperture. The video voltage output is non-linear, being proportional to the input irradiance to the .74 power. Verification of these operating parameters was achieved using concurrent imaging and radiometric measurements. This same technique was also used to map the surface of the intensifier vidicon for uniformity. A point source was placed in a number of geometric locations, to repeatedly impinge on the major areas of the vidicon surface and the resultant analog voltage of the video waveform was then compared to the measured radiometric value of the input source.

Within the "usable" 80% of the surface area of the vidicon, uniformity is ± 5%, worst case. There are some areas at the edge of the vidicon with variations of ± 10%.

An alternate mode of operation for the LS^3 is achieved by "short-circuiting" the high voltage power supply and forcing the unit to operate as a standard image-intensified vidicon camera. In either mode, the spectral response of the unit is S-1 or roughly from .35 to 1.1 microns as shown in Figure 2.

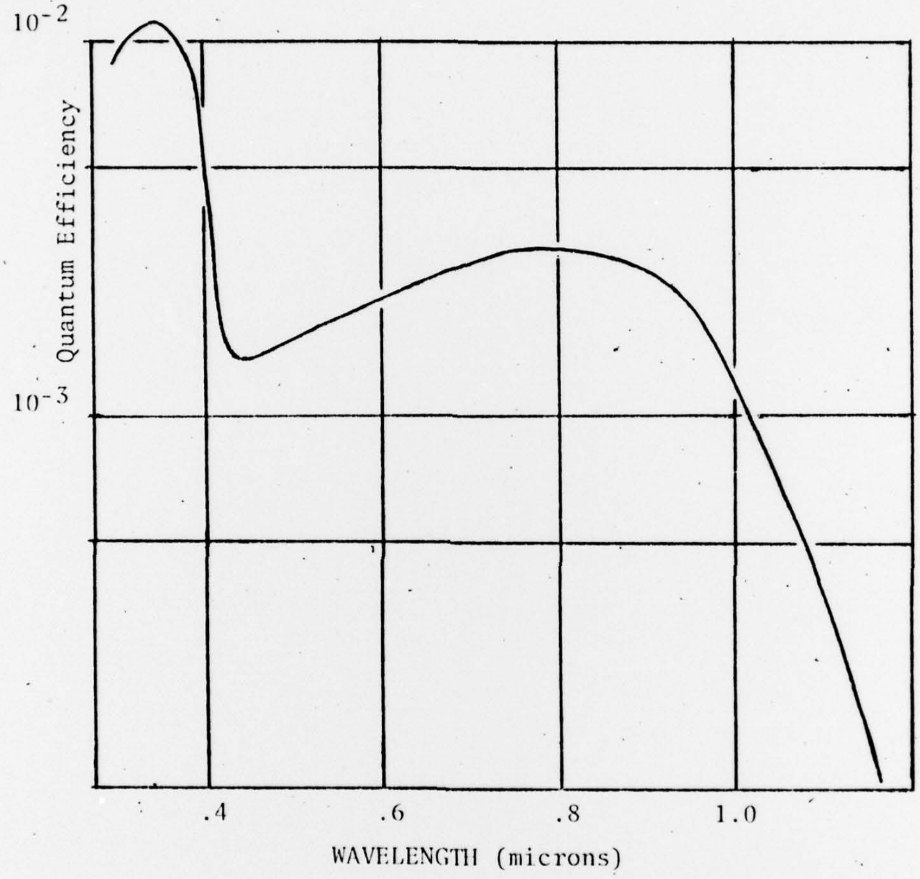

Figure 2 - Image Intensifier Spectral Response

If necessary, the unit could be used to test any type of laser in this spectral band; however, its primary function is in evaluating 1.06 micron laser designators.

The culmination of the LS^3 methodology development came during the recent (summer of 1977) DT-II test of the Ground Laser Locator Designator (GLLD). Three basic categories of data were collected during this test: pointing and tracking data, energy distribution or mapping data, and transmission data through smoke and dust clouds. All data were collected from flat panel targets as sketched in Figure 3.

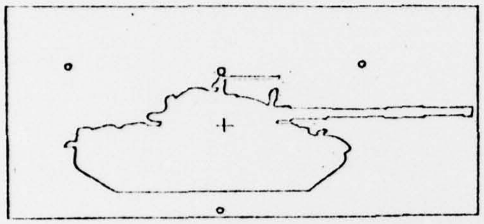

Figure 3a-Test Target, Side Silhouette with Marked Aimpoint

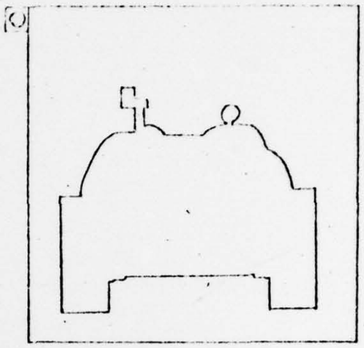

Figure 3b-Test Target Front Silhouette

Figure 3a shows a side silhouette of a full-scale (dimensionally) Soviet T-62 tank. Three beacons (flood lamps) were required to scale data and establish a frame of reference during moving target data collection sequences. The target measures 36 feet (long) by 16 feet (high) and is mounted on a 40 foot long flat bed trailer. The trailer also carries its own motor generator to provide power for the beacons and an inserted steel panel equipped with heater strips to provide for day and night tracking.

The data taken are ultimately used to calculate an energy centroid position for each laser pulse arriving at the target. This necessitated some other design considerations. Specifically, the flatness of the target is important to maintaining the uniformity of reflections. Also the target presented to the GLLD operator must be of high contrast, but the reflectivity of the target at 1.06 microns must be uniform so that the data is not perturbed at the edges of the silhouette. Paint for the target was painstakingly blended in the laboratory until three colors, presenting high visual contrast, within 1% of the same reflectivity at 1.06 micron were developed.

Figure 3b is a frontview silhouette (full-scale) of the T-62 tank. This target is presented on a 12 foot square panel and was used in data collection for stationary "pointing" data runs, energy mapping runs, and transmission tests through smoke and dust.

Stationary runs were done at ranges to 9 Km. Energy maps were gathered at 3 and 5 Km under low, moderate and high scintillation conditions. Tracking or moving target runs, were done at slow, variable and high speeds at ranges to 7 Km. All data taken during the test were collected on video tape. The recorder used was a standard one-inch International Video Corporation (IVC model 800A recorder). IRIG-B time was encoded on one of the two audio channels of the recorder. The second audio channel was used for voice annotation of the data. Video data tapes were then transferred to the ARMTE Image Analysis System for processing.

As mentioned earlier, concurrent to the development of the LS^3 data acquisition system, emphasis was being placed on utilization of a common processing facility for a wide variety of data collected in, or transformed into, an image format. The system which eventually grew out of this philosophy is shown in Figure 4 below.

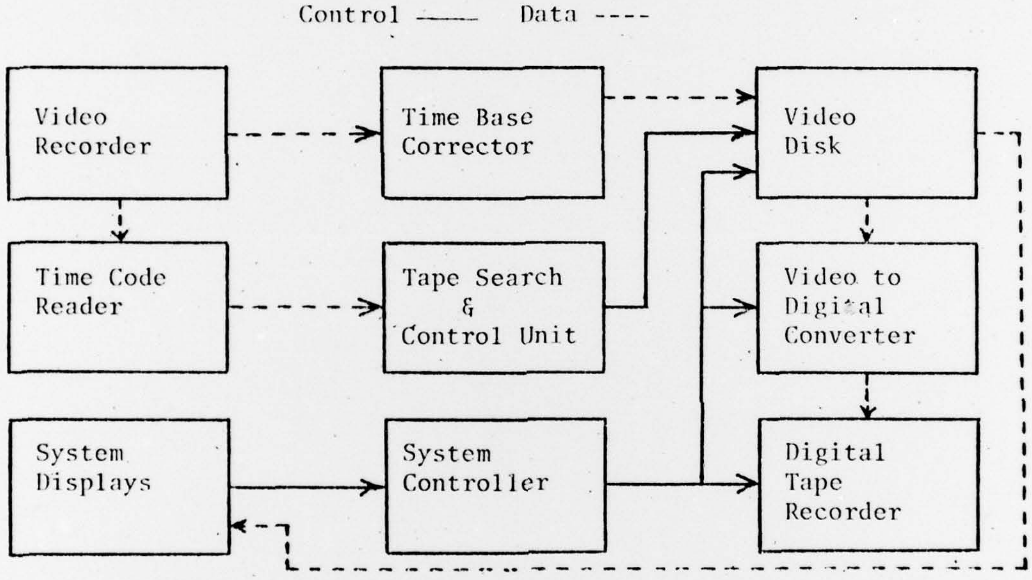

Figure 4 - Data Conversion/Processing System Configuration

The video tape data described above are input to the system through a Time Base Corrector, required to match the recorder and system synchronization. An IVC Model 875 recorder is needed since it is capstan-servoed, a requirement in matching synchronization. The tape is read onto an analog video disk in bursts of 5 seconds. Timing is controlled by a tape search unit, enabling the operator to exactly match four five-second data segments into a complete twenty second data run.

Once the data are stored on the analog video disk, they are then digitized and stored again in 7-tracks on digital tape. Digitizing is done vertically, one field at a time. Figure 5 represents the data format as it would appear on a television monitor.

```
t-Trace Field
r-Retrace Field

tttttttttttttttttt..............
rrrrrrrrrrrrrr..................
ttttttttttt.....................
rrrrrrrrr.......................
tttttttt........................
rrrrrrr.........................
tttttt..........................
rrrr............................
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Figure 5 - Television Data Format

For full-frame digitizing, the trace field is first converted as a series of vertical lines; then the retrace field in a similar manner. While this pattern is somewhat inconvenient, it provides the maximum time efficiency for re-recording the digital data on 7-track tapes. Digitizing a full frame (both fields) requires 43 seconds.

In most cases, the actual data exists in a smaller area of the picture. In order to save time and tape space, a series of "windows", controlled by the systems mini-computer, are used. The "windows" are generally 200 X 200 or 100 X 100 matrices which may be positioned on the overall 680 X 512 point matrix of the picture. In the case of data reduction for a pulsed laser designator, the windows used are single field. This is necessary to lend any real credence to the data from the LS^3 system described above. If the pulse repitition frequency (prf) of the laser is an even factor of sixty, dividing into sixty an even number of times, such as 5, 6, 10, 15, or 30 pulses per second, the first, or trace, field of an image will be valid. The gating of the intensifier affects only the input of the image data while the vidicon is read in a free-running mode at 60 fields per second. If, however, the prf is an odd factor of 60, such as 12 or 20, the trace or retrace field may be valid, depending upon the position of the pulse frame in the data sequence.

The subroutines used in digitizing a given data run is then dependent both on the laser device prf for the particular pointing/tracking sequence, the geometry of the data collection system, and the average position of the data on the display screen. The equipment operator selects the appropriate factors and the 5-second quarter segment of the data run is then digitized. Once the operator selections are made, the balance of the work is assumed by the digital system's mini-computer controller. Based upon the pre-programmed guidance of the operator, the analog disk is incremented in the required steps to maintain the data sequence, and appropriate fields are digitized and stored in 4096 word blocks at eight bits per word. Header records are used with the data to identify all the necessary ancillary information for ultimate processing, including run sequence number, environmental conditions - if appropriate, operator and device identifiers, and the starting address of the digital matrix coordinates - if required. The bulk of the data on a roll of tape consists of intensity of "gray-scale" values of the various picture elements or "pixels". These values are stored in eight bits, providing a range of 256 possible levels. They are the only required values since the geometric coordinates are known from the known sequencing of the digitizer.

Once the operator has a complete data run of 20 seconds stored on 7-track digital tape, the tapes are transferred to the range's large-scale computers for processing. Dependent upon the class of data, i.e. mapping, tracking, or transmission, different reduction programs are applied.

Energy mapping is, of course, the most obvious of applications. No other approach can readily compete with the image camera for the collection of energy mapping data. The only alternative would be a massive array of detectors (348,000)to compete with the camera on a 1 to 1 basis) which would be far too expensive to buy and a nightmare to use.

Energy map data are read into the large-scale computer one frame (field) at a time. Using a pre-determined set of calibration factors for the various intensity levels, the energy contained with the reflected spot is calculated as a weighted sum. This value is then compared to the anticipated energy at the target, considering laser output, range to target, and atmospheric conditions. The result is one data point of the energy versus time data plot for the map run. These plots are expressed as % minimum anticipated energy vs. time, keeping the data unclassified for ease of handling. Ninety-nine more such frames are then processed to produce the plot. The time interval between data points is then .2 seconds. In addition to the energy calculation, the x and y coordinates of the energy centroid are also calculated for each pulse of the data run and appropriate plots are generated.

The primary purpose of energy mapping in the Development Test II (DT-II) of the GLLD system was to acquire data for use in theoretical mathematical models of the effects of the Atmospheric Structure Coefficient (C_n2) on the transmission of the laser radiation. To this end, in addition to data plots, energy map data were reformatted into 200 X 200 point matrices representative of the spatial distribution of energy levels for direct insertion into digital mathematical models. The in-depth analysis of this data is being done at the Electronics Research and Development Command(ERADCOM)

Fort Monmouth, NJ and by members of the Laser Designator Weapons System Simulation (LDWSS) group at the Missile Research and Development Command (MIRADCOM), Redstone Arsenal, AL. Their results were not available at this writing; however, presented below in Figure 6 are the energy versus time plots for a laser device at 3Km range under low, moderate, and [illegible] scintillation conditions.

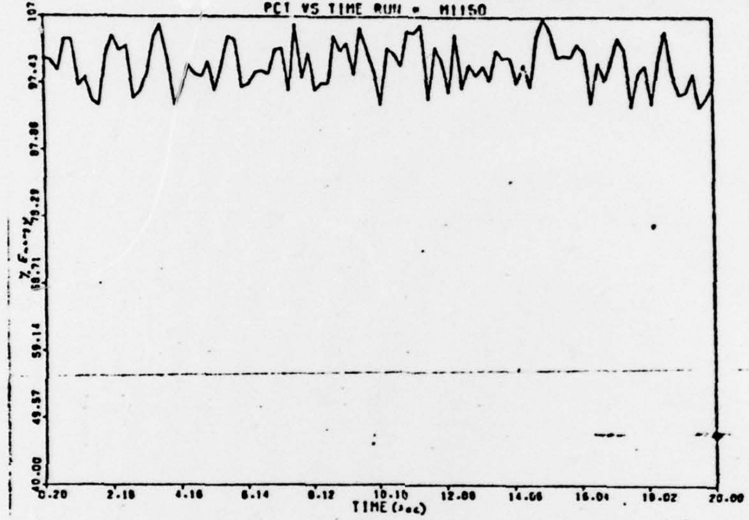

Figure 6a- Weak C_n^2, Percent Energy vs Time

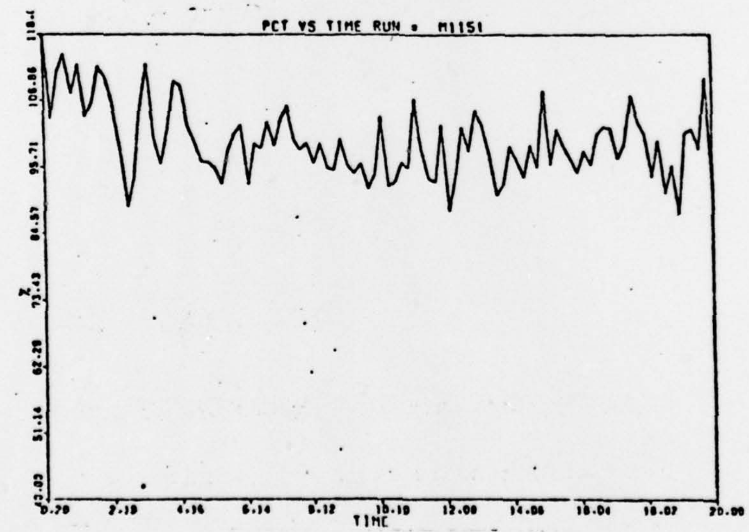

Figure 6b-Moderate C_n^2, Percent Energy vs Time

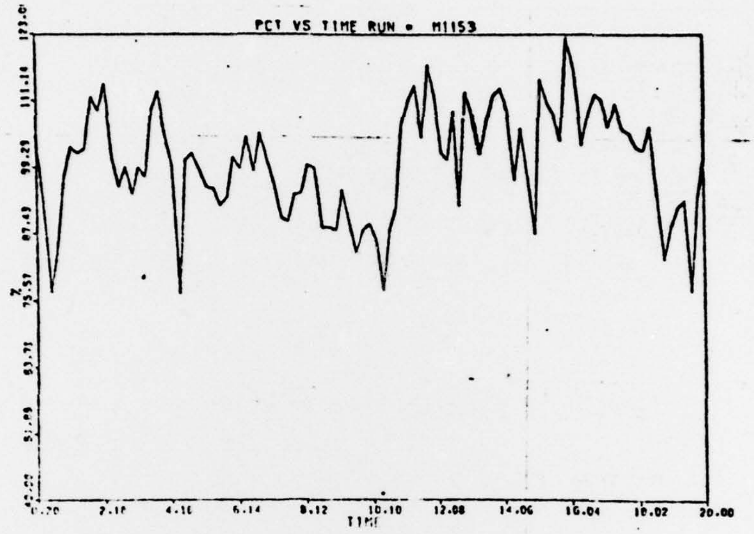

Figure 6c-Strong C_n^2, Percent Energy vs Time

Due to the magnitude of the apparent energy fluctuations, the follow-up test run on a 50 pulse sample of near-field (3 meters) data. The resultant % energy vs time plot is shown below in Figure 7.

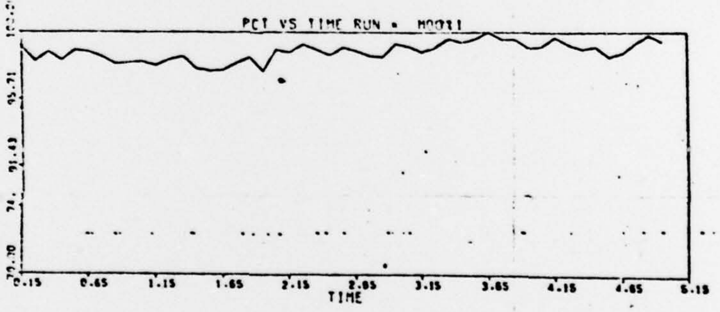

Figure 7-Near Field (3 meters), Percent Energy vs time

Data for laser transmission through smoke and dust are processed in much the same manner as the energy maps and portrayed in similar data plots. Transmission of laser energy through smoke apparently correlated well with previously established laboratory results.

The bulk of the data collection/reduction for GLLD DT-II involved system pointing and tracking accuracy. Nearly two hundred data runs (twenty seconds each) were processed, representing a variety of target and designator configurations. Use of the gated imaging system was desirable in that the actual energy centroid can be calculated from the image and the energy centroid is the track point of a homing system. Substantial conflict about the adequacy of the LS^3 system and its subsequent reduction hardware and software existed prior to the GLLD DT-II, and a series of experiments were conducted prior to the testing phase to resolve this conflict. Accuracy of the calculations of centroid position was questioned. This was resolved by imaging known sources and carrying the process through to its conclusion. The results showed an uncertainty of 1/2 of a pixel, the predicted uncertainty derived from the data conversion process. A second source of concern was the conversion of coordinates and scaling on the moving target, Figure 3a above. The target was run over a typical course with a fixed source mounted at the aimpoint, then at known coordinates in each "quadrant" of a set of axes zeroed at the aimpoint. The results demonstrated an accuracy limit of 25% of the previously established accuracy requirement.

Processing data for pointing and tracking accuracy requires two major subroutines, coordinate conversion/scaling, and centroid position scaling. For a fixed target, the coordinate set and scale factors are already known; however, each image for a moving target, or tracking, run may have a different frome of reference. Since all target roads were flat, no vertical corrections were required. Horizontal corrections (cosine function) were required, as were scale factors as the target first approached and then receded from the data collection system.

Once these corrections are made, the location of each pixel of a given data frame relative to the target aim point is unknown, and the energy centroid position of the laser spot can be calculated.

Using the representative printed version of a typical laser return as displayed in alphanumeric form below, the energy centroid coordinates are determined, in pixels, using the following expression:

$$X_E = \frac{\sum_i A_i \quad E_i \quad X_i}{\sum_i A_i \quad E_i} \qquad (1)$$

$$Y_E = \frac{\sum_i A_i \quad E_i \quad Y_i}{\sum_i A_i \quad E_i} \qquad (2)$$

Figure 8-Energy Level Distribution in a Reflected Laser Spot

where X_E, Y_E are the X and Y coordinates of the energy centroids, Ai is the number of pixels in i^{th} iso-energy band, and Ei is the intensity scaling factor of the i^{th} iso-energy band.

Plots of centroid position (X and Y) are then generated versus time for each twenty second data run. Subsequent statistical calculations are used to determine the mean and standard deviation in X and Y for the entire data run. A typical output plot is shown below in Figure 9.

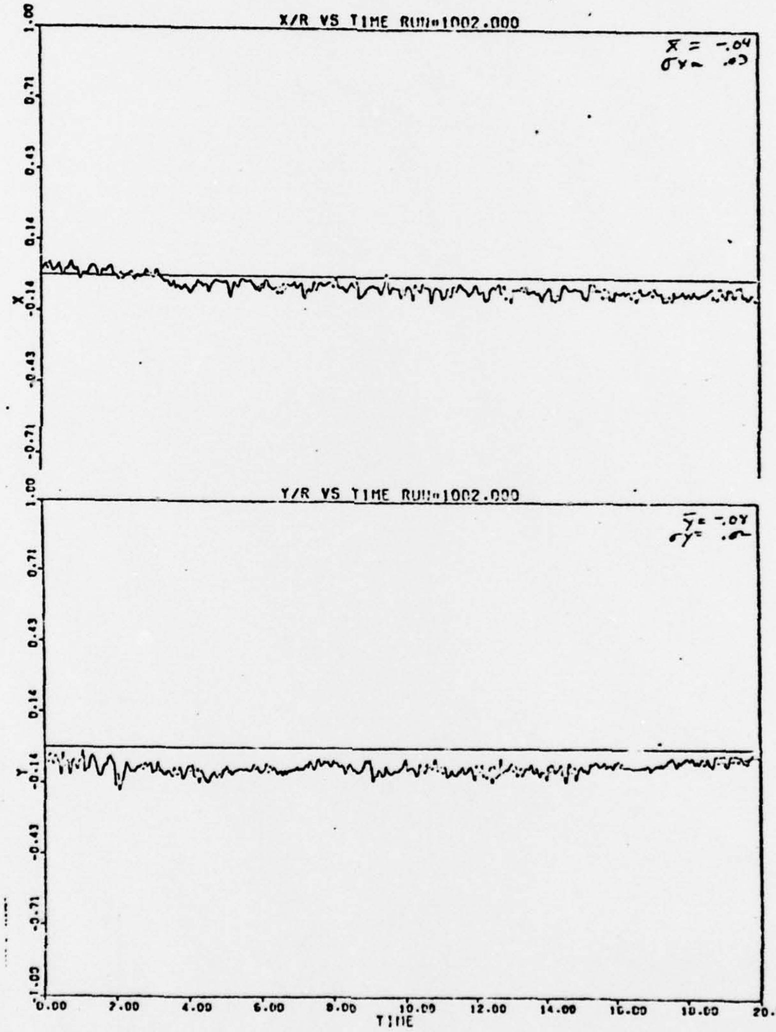

Figure 9-Tracking Accuracy in X and Y

In addition to the plots and calculations referenced above, digital tapes of the X, Y data were forwarded to MIRADCOM for direct insertion into the LDWSS operating model.

Since the GLLD test is now history, let me conclude by discussing a few of the lessons learned from the effort, and resulting plans for system improvement. First, the sensor used, the LS^3 system, proved reliable but the optical limitations imposed by the physical length of a moving target data run suggests addition of at least one more, second-generation LS^3. That action is now in the planning process.

The second lesson learned was in the processing phase. Separate conversion and processing facilities are not practical. Competing requirements on the large-scale range computer creates turn-around time problems, and carrying a floating inventory of over 300 rolls of digital tape is a bookkeeper's nightmare. Data tapes were actually lost in the shuffle and had to be redigitized. Two still haven't turned up. This problem is now being solved by the addition of a dedicated, mid-sized computer system to the existing data conversion system. Once hardware and software interfaces are completed, we will be facing a bright and busy future in the evaluation of pulsed laser performance.