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GEOMETRIC AND TEMPORAL CHARACTERIZATION OF BATTLEFIELD SMOKE AND DUST BY MULTISPECTRAL DIGITAL IMAGE ANALYSIS (U)

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1. INTRODUCTION

The objective of this research is to design and demonstrate an automated technique for: the identification of smoke and dust types observed in simulated battlefield environments; the derivation of the geometry and external dynamics of these features; and prediction of the trajectory, expansion, and dispersion rates with time. The premise is that the use of currently operational passive multispectral image collection systems - with output that is functional in a digital processing mode - will reveal information that either cannot be obtained from data acquired by conventional analog techniques such as photography or at least not as quickly and conveniently for the purpose of effectiveness. An extension of this effort will be to correlate this information with particulate and transmissivity measurements in order to accurately quantify the cloud surface into values that are feasible as input to transport and diffusion modeling.

2. DATA DESCRIPTION AND ACQUISITION

The imaged data input to the techniques development are analog tape recorded raster-scan pictures of the smoke/dust scenes. These records result from observations of the field scenes with optical-vidicon sensors that frame record at rates of 60 per second and are capable of measurement in numerous wavelength bandpasses. The records are digitized to 9-track computer compatible tapes in arrays of 250 x 300 8-bit data samples. The basic field data acquisition configuration for previous field tests has consisted of a bank of four boresighted sensors recording simultaneously in wavelengths of $0.5\mu - 0.7\mu$, $1.06\mu \pm 0.2\mu$, $3.0\mu - 5.0\mu$, and $8.0\mu - 14.0\mu$. In the field tests to date, data was recorded from two stations positioned approximately 70 degrees apart in perspective of the smoke/dust ignition location and provided eight simultaneous image data sets. Over 100 smoke/dust events have been observed and recorded during participation in the following field experiments:

Dirt I. White Sands Missile Range, September 1978, sponsored by the US Army Atmospheric Sciences Laboratory, 32 events, HE.

Smoke Week II. Eglin AFB, October 1978, sponsored by the PM Smoke Office, 30 events, smokes of all types.

Dirt II. White Sands Missile Range, August 1979, sponsored by the US Army Atmospheric Sciences Laboratory, 40 events, HE - 105mm, 155mm, and C-4.

Dirt III. Fort Polk, Louisiana, April and May 1980, cosponsored by the US Army Atmospheric Sciences Laboratory and the US Army Corps of Engineers, 70 events, HE - 155mm, 105mm, and C-4.

Additional data will be acquired from the Smoke Week III experiment to be conducted at Eglin AFB in early August 1980 sponsored by the PM Smoke Office.

The time incrementation selected for digitization of the analog image records of the earlier field experiments varied due to the uncertainty of what selection would adequately and efficiently describe the growth history of the feature. Prior to the Dirt-II field test, it was established that an incrementation of 0.1 second for the first second of the event and 0.5 second from 1.0 to 10.0 seconds would achieve a comprehensive observation of the effects of the initial blast phase of the event. The externally apparent physical changes that occurred during the buoyant and transport phases were in most cases suitably described with a 2.0-second incrementation - from 10.0 seconds into the event until dissipation. All analog tapes have been retained should the need arise to study selected events in finer detail.

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3. TECHNIQUE DEVELOPMENT FOR EXTRACTION OF CLOUD DIMENSIONS

The initial issue undertaken upon availability of the first digitized image data sets of the Dirt-I events was the design of a scheme for isolation of the dust feature from the remainder of the scene. A variety of feature-isolation algorithms was constructed and applied to the least difficult condition - sequential scenes acquired from one sensor station and in one bandpass. The procedure fundamental to the solution was to subtract the gray level values of the array of picture elements of a scene recorded immediately prior to ignition from those corresponding elements in scenes that followed and contained the dust feature. A refinement of this approach was developed later; the gray level slope gradient was computed for the adjacent picture elements in each of the scenes prior to the subtraction. This step tends to subdue the effects of both the high frequency noise and picture wide, average gray level value differences between scenes (figure 1).

Now that the picture elements which comprise the feature have been isolated and consequently, the perimeter well defined, the matter of calculating the geometry is relatively simple. The area of the feature is the product of the number of picture elements and the spatial dimension per picture element as a function of the sensor resolution. The height and width of the feature are the maximum spatial separations in the vertical and horizontal, respectively, and again the number of picture elements times resolution. For the purpose of temporal tracking of the feature and for statistical correlation of growth with time, it was determined that the most efficient and accurate means would be to fit an ellipse to the picture elements that comprise the feature perimeter. The centroid of this ellipse would then be the best estimate of the apparent center of mass; therefore, distance and height relationships as a function of time could be derived by counting picture element separations. Typical computational output are these kinds of values: major axis, minor axis, inclination of the major axis, and the height and lateral offset of the centroid from the location of ignition (figures 2 and 3).

An additional operation is the relative quantization of the cloud surface reflectance. This is being treated by one of two methods: by contouring the raw intensity array, or by contouring the slope gradient array that results from the subtraction procedure. In either case, the contour interval is selected to portray a reasonable representation of the luminance distribution

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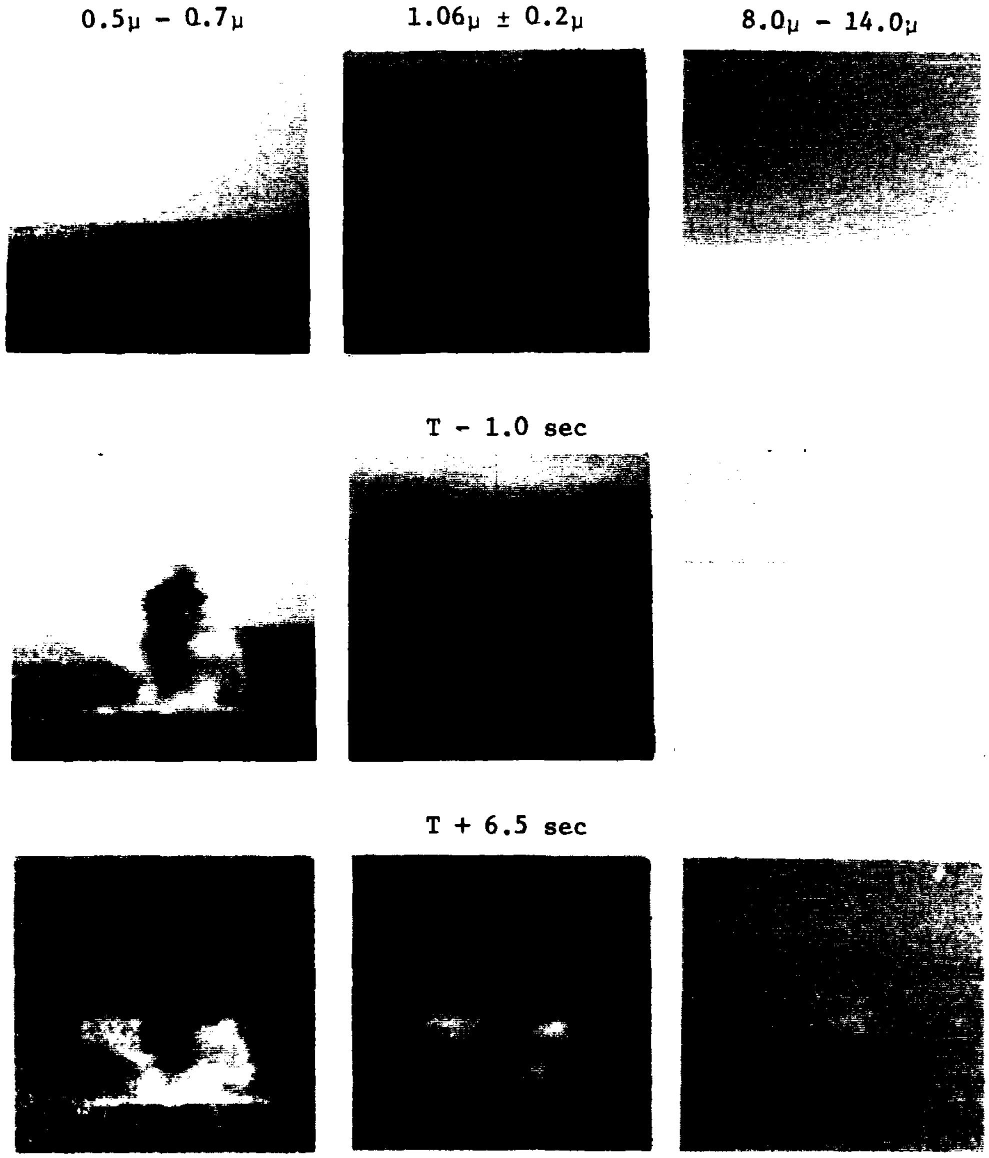

DIRT-II, WSMR - Aug 79 EVENT B-19, 155mm Static

Figure 1. Computer array subtraction.

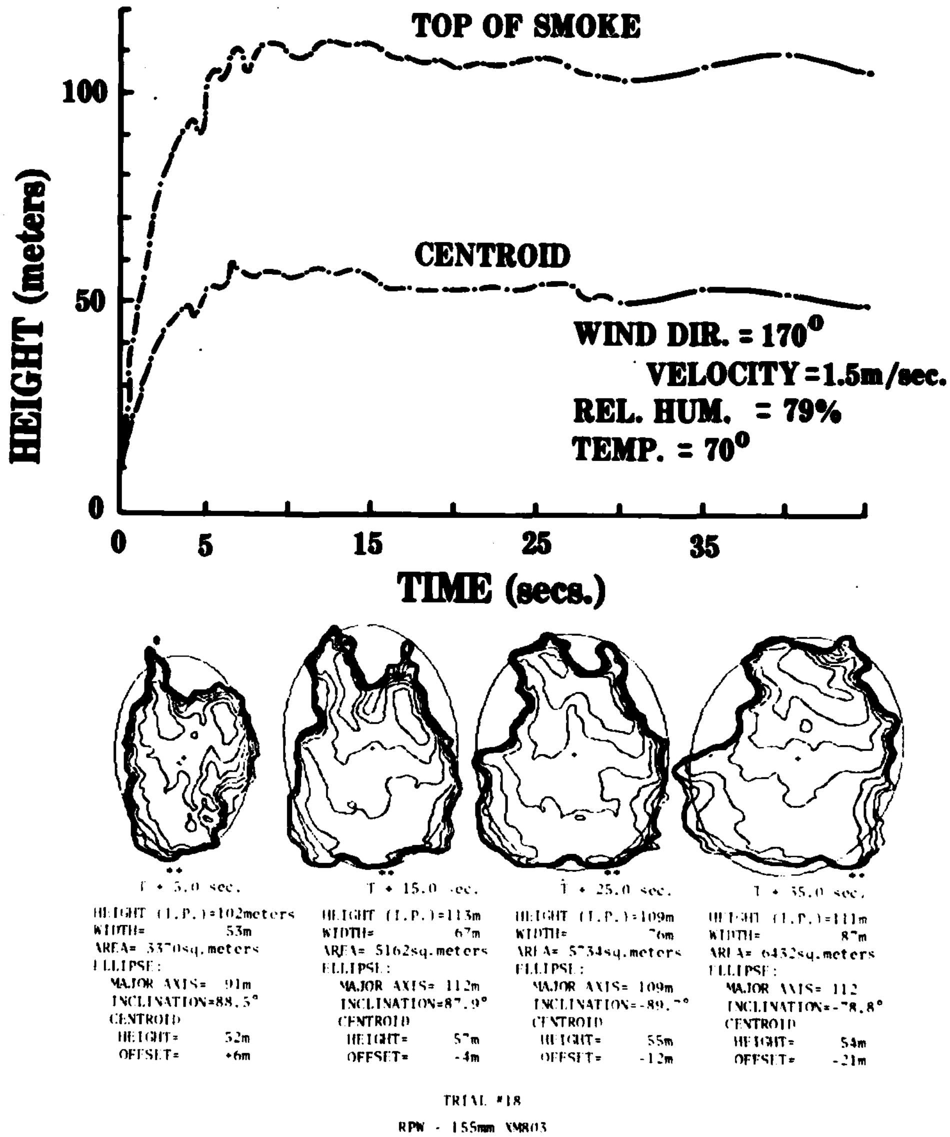

Figure 2. Smoke Week II, Eglin AFB, example of geometry measurements.

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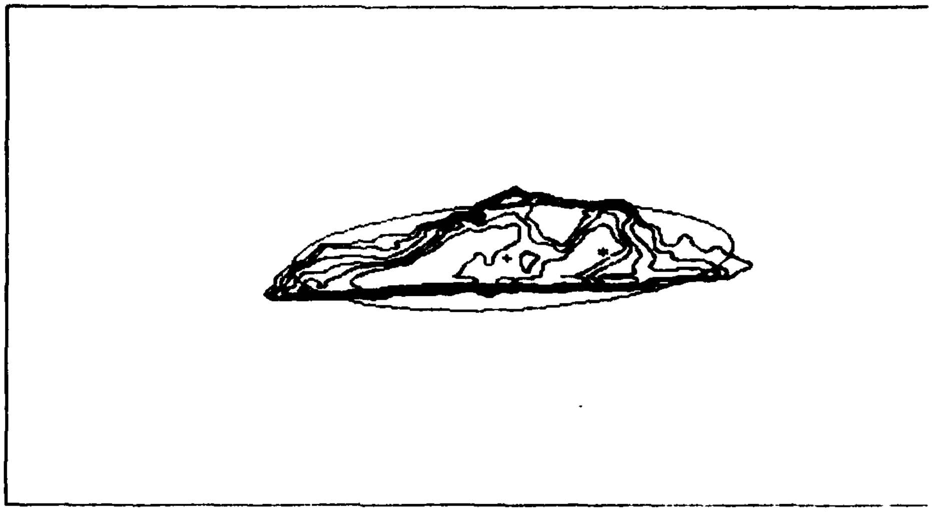
DIRT II EVENT # AB7

1857 Z 07-18-79 STATION # 1 SENSOR= 0.5-0.7 MICRON

T+ 36.0



HEIGHT(ABOVE DETONATION PT.) =	18.0M	HEIGHT OF CENTROID=	9.M
WIDTH(MAX. HORIZONTAL EXTENT)=	57.0M	LATERAL OFFSET	=123.M
VERTICAL EXTENT =	15.0M	AXES	= 57., 16 M
AREA =	471.3SQM	INCLINATION	= -3.7 DEG

CENTROID OF BUOYANT PORTION OF CLOUD HEIGHT= 10.M OFFSET=134.M
HORIZONTAL EXTENT AT 7 METERS ABOVE SURFACE= 53.M
HOR. EXTENT OF LINE CONTAINING PT. OF MAX. OFFSET OF LEADING EDGE= 46.M
SHEAR(HOR. DISTANCE BETWEEN PT. OF MAX. OFFSET AND PT. AT 7 METERS)= -3.M

** = DETONATION POINT
+ = CENTROID OF PRIMARY ELLIPSE
* = CENTROID OF BOUYANT PORTION OF CLOUD

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Figure 3. DIRT-II, White Sands Missile Range, New Mexico, example of geometry measurements.

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of the surface. In the future, an effort will be made to calibrate selected levels with transmissivity. The spatial integrity of the array is such that if the picture element location is known where an absolute measurement has been obtained, then extrapolation is feasible throughout the scene array.

In the majority of cases, the use of data from one bandpass, particularly that from the 1.06μ sensors, has proven satisfactory for extracting two-dimensional feature geometry. Occasionally, when the scene contrast range is compressed, as evidenced with the minimal lighting conditions found in very early morning or early evening, some difficulty may occur in the separation of feature from background. Therefore, the next logical progression in techniques development was to treat multiple bandpasses in search of compensating strengths.

The prerequisite of multiband analysis is accurate spatial registration and common scaling of the digital arrays. Every picture element in the array of one band must match the corresponding picture elements in the other arrays - both positionally in the image plane and in scale. The design and utilization of tailored interpolation algorithms achieved the necessary relative scaling and magnification or reduction of the arrays.

Two different approaches have been tested with pairs of time coincident data arrays (recorded from the 0.5μ to 0.7μ and 1.06μ spectral regions). One method, initially similar to the single bandpass technique discussed above, performs array subtraction on each of the two spectral scenes from their respective scenes prior to ignition. Those picture element locations from one spectral array that indicate presence of the dust feature are summed with the residual from the other bandpass. The resultant array produces a "window" (a discrimination of the feature from all other characteristics of the scene). This window, or negative mask, can either be used directly as a definition of boundary for computation of the dimensional parameters of the feature, or superimposed upon the raw data array for either of the two bandpasses, thereby permitting relative contouring of the selected wavelength.

The second approach, called a multiband training-field classification technique, is one commonly applied in other disciplines (forestry, crop identification, etc.). It interprets the interrelationship of two (or more) bandpasses at each picture element location. This relationship is first established by observing or evaluating the respective gray level ranges found within subarrays dimensioned in the preignition scene where the object features are known (sky, terrain, etc.). Now, every feature is classified and the "signature" pairs of spectral gray level ranges are saved for comparison with each picture-element-pair of a new scene. This comparison, on a picture element position basis, will flag any anomaly or the presence of an object foreign to the "training" scheme and note the location of that picture element. The accumulation of these positions will define the portion of the scene that is dust/smoke (figure 2). In turn, an automatic evaluation of the "anomalous" gray-level ranges will establish a new feature signature that will be used in the classification of subsequent scenes.

The 8.0μ to 14.0μ data has been treated strictly with the single-band extraction technique for definition of boundary and the results registered with the geometry calculations derived by one of the techniques discussed above (figure 4). The predictable fact that the perimeter of the 8.0μ to 14.0μ bandpass is seldom found coincidental with feature perimeters calculated from the other bands was learned very early in this research. In most cases, especially with high explosives and white phosphorous, the temperature band is greater in extent and area during the initial phase of the event and then subsides rather rapidly back to within the particulate perimeter. There appears to be a distinctive correlation of this dissipation rate to the type of smoke, and in the case of the high explosive, to the size of the charge.

Only preliminary results have been achieved in recently instituted attempts to correlate data acquired simultaneously from two widely separated sensor perspectives. Perfection of a method is one of the primary goals of this research, realizing that the results will provide a means of accurately calculating the volume and drift direction of the feature. The reasonable assumption is that the ellipse is the best generalized estimate of the shape of the feature and that the centroid is the best estimate of the apparent center of mass. The approach is to project each of the two ellipses from their respective two dimension domains into three dimension space and to translate the respective centroids to a common point space position, thereby establishing the origin for the three dimensional coordinate system. The angular relationships and dimensions of the two pairs of axes will fix

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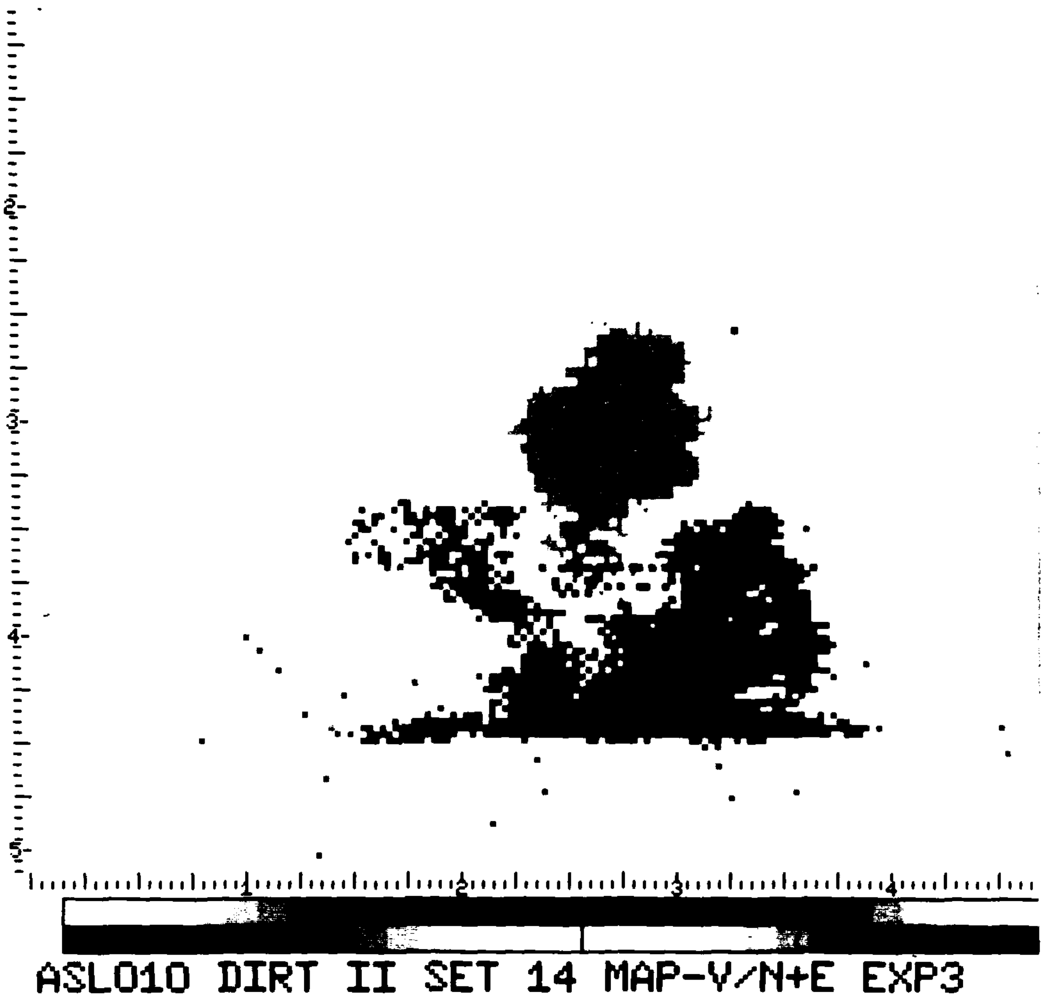

DIRT-II, WSMR - Aug 79 EVENT B-19, 155mm Static
T+6.5sec.

Smoke Predominates	=	light gray
Dust Predominates	=	dark gray
Temperature Hotter Than Ambiant	=	black

Figure 4. Multiband analysis technique (0.5μ - 0.7μ, 1.06μ ± 0.2μ, 8.0μ - 14.0μ).

points in the coordinate system at the surface of an ellipsoid. The ellipsoid mass, orientation, and unit translation with time would itself be the best estimate of the three dimensional character of the smoke or dust feature. Other techniques will be tried: photogrammetric mapping of the actual surface and statistical extrapolation of all or some of the dimensions calculated by the techniques discussed earlier, etc.

4. STATISTICAL ANALYSIS

Trends in the parameters resulting from dimensional analysis of the Dirt and Smoke Week field experiments are being evaluated for the purpose of designing statistical schemes for identifying the type and size of the source of the feature and prediction of the growth dimensions and transport distance with time (figure 5).

The events of the three Dirt tests were numerous detonations of C-4, and static and tube-delivered 155mm and 105mm HE rounds. The static rounds were used to simulate a variety of impact orientations by positioning a single round/event either at the surface or at a known subsurface depth and in various angular configurations in respect to the surface. The resultant dust/smoke clouds were observed to effect fairly characteristic dimensions, shapes, sizes, and temperature extinction rates. The amplitudes of these measurements were controlled by the soil and vegetation characteristics of the locality but, interestingly, the meteorology did not distort the source-related dynamics of the feature until at least 8 or 10 seconds into the event. In this short time frame, certain of the dimensional parameters associated with given sets of source conditions have behaved with measurable consistency, hence, the provision of a means for type classification.

The algorithm is a decision comparison of the ratios of combinations of the computed slopes for segments of curves derived from a time sequence of each of the dimension measurements extracted by one of the techniques described earlier in the paper. The comparison is made with ratio values known to correspond to a given set of source conditions. The parameters found most useful so far are these:

a_s/b_s = ratio of the slopes of the major and minor axes

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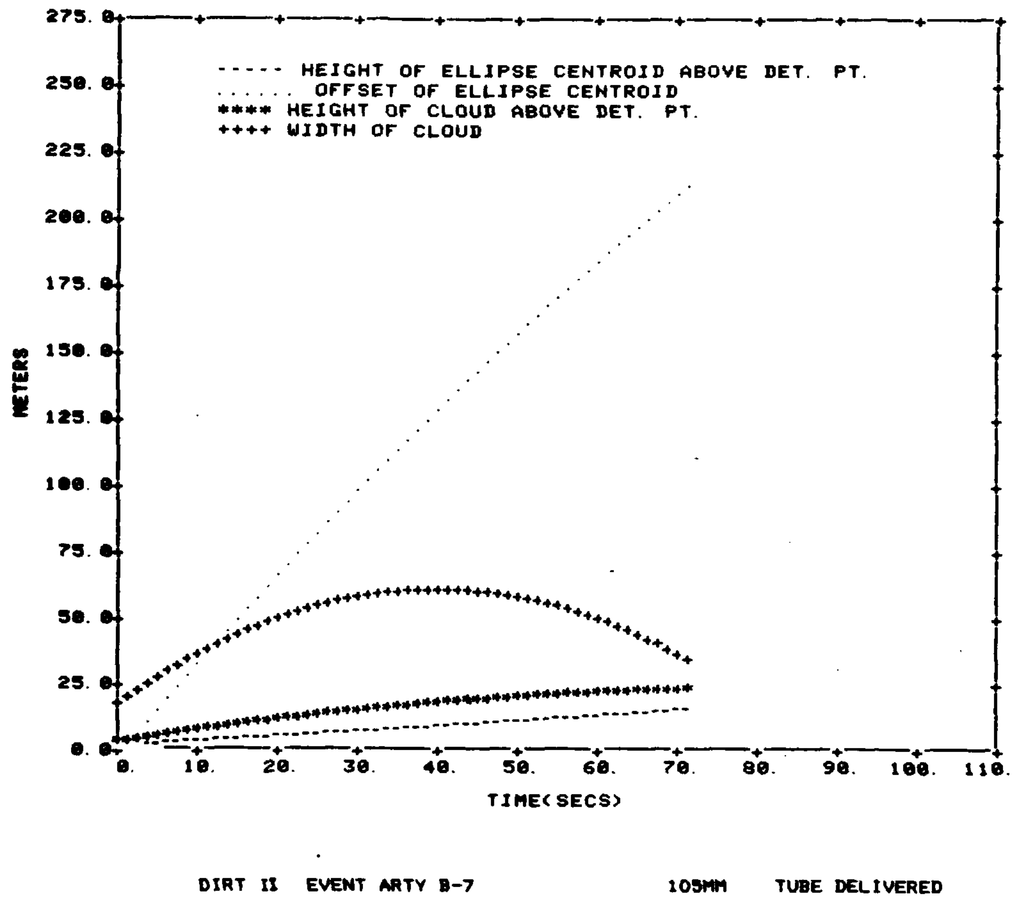

Figure 5. Geometry/time.

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Y_s/x_s = ratio of the slopes of the height of the centroid above a horizontal plane containing the ignition location and the transport (offset) distance from the ignition point

I_s/x_s = ratio of slopes of the inclination of the major axis and the transport distance.

Experimentation is under way to use numerous combinations of these slope parameters in a multidimensional space coordinate system, whereby defined "cluster" classification separations may enhance the decision accuracy.

The establishment of a procedure for prediction of feature growth and trajectory track with time has been approached in three ways: direct extrapolation of a quadratic fit to the first few seconds accumulation of computed dimension data and the extrapolation of the slopes from short-time segments of least-square curves representative of the earlier dimensions. Either of these approaches works satisfactorily for predictions up to 15 to 20 seconds subsequent to the time of the calculation (data acquisition time) but can become erratic for greater time spans. The most promising approach currently being investigated is the application of a stochastic predictor/corrector interpreter of the early data. The one being tested is the "Kalman filter" and preliminary results indicate the possibility of extrapolation at least as far in advance as 2 minutes from the calculation.

5. SUMMARY OF PROJECT STATUS AND PROBLEMS

As with most research projects, the predominate problems are an insufficient base of controlled test data and the quality of the data itself. The data base has begun to expand both in volume and variety due to increasing interest in the technique and the results and, consequently, invitations for participation in many field tests. As for data quality, the acquisition and the computer handling procedures have improved progressively and the availability of sensors with improved resolution and signal-to-noise ratios is under review. The signal-to-noise related problems have required the development of special data enhancement algorithms that would be unnecessary if the sensor output was of a better quality.

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The battlefield environment modeling researchers have set a requirement for computation of the geometry for all events from all field tests in which we participate. The information being furnished reflects the status of our techniques research and computer program engineering - the more recent the information, the more accurate and comprehensive.

At this stage, the technique for computing the cloud geometry, derived from data acquired from one perspective and two bandpasses, is functional with only computer data handling efficiency still in work. The registration scheme for matching the feature perimeter of the thermal bandpass with the geometry is operational. The technique for extracting three dimensional information from two or more perspectives is yet in the preliminary stages of development; early testing with a few data sets have proven the feasibility. The feature identification scheme functions for nearly all test data on hand, but at this stage, with a high degree of interactivity with the computer. Adaption of an automatic procedure is in a very early level of development. The method for predicting feature growth and transport is in a similar state of design.

There are many important subinvestigations of this research that are in planning. A fundamental need is the capability to transform the output of the techniques discussed here to match the output of specific surveillance and designator systems currently in battlefield inventory. Although the data used in this project are acquired in wavelength ranges of the spectrum common to most fielded systems, a refinement of accuracy could be achieved if the total systems response could be mathematically duplicated. How this can be approached has been discussed with many experts in the field of optical/spectral calibration and a preliminary course of action is in design.

Another logical progression will be to assist in updating the current smoke munitions expenditure procedures as required to "smoke" a given area under given conditions of meteorology and tactical perspective.

One more investigation of many that are envisioned would be in support of artillery by providing a means to measure and, as a result, correct for the wind effects in the vicinity of the target. A quick evaluation of the "local" wind profile could be achieved by the expenditure of a single HE round.

6. CONCLUSIONS

Among the many questions presented to a field commander regarding the atmospheric environment of the battlefield are these: What is the type of contaminant? Who does it belong to? How long will it be there? What area will it affect during transport? How much area will it obscure? Which of my electro-optical systems will it incapacitate? Which of the enemy's?

The purpose of this project is to assist in answering these questions - either by empirical input to current efforts in modeling design or as a means of validation of these designs. Another possibility might be the design of a compact field system that could provide answers directly (passive multiband sensors, a special purpose microprocessor and software, and a small graphics display).

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