Use of Pattern Recognition to Validate Test Data

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Theme

THIS paper outlines the methods and experience obtained in applying Pattern Recognition techniques to the validation, processing, and analysis of test data in an operational environment. The first practical problem described involves trajectory analysis, prediction, and validation of models using preflight and postflight data. Two other problems relate to comparative data analysis and techniques to generate hypotheses in multidimensional problems involving manufacturing processes whereby items can be separated into success and failure groups. While the mathematical techniques presented here are standard, their use to obtain solutions to actual problems should be of interest.

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Model validation can be described quite simply as the effort required to demonstrate that one has a valid computer simulation model. For simple models and inexpensive test programs, this task can generally be accomplished with relative ease. However, rocket tests are expensive and trajectory model simulations required for accurate performance determinations are quite complicated. This requires making use of all possible information from each flight test. The need is quite clear for a rapid and comprehensive technique to identify problem areas in the computer models used for simulation of the rocket trajectories (which are flown with different payloads and a variety of initial and final conditions).

A collection of the computer techniques which were developed in response to the preceding requirements is called PROBE (Pattern Recognition On-line Basic Evaluator), and this paper describes the methods and experience obtained in using PROBE in an operational environment. PROBE consists of a set of computer tools which is primarily concerned with organizing and displaying information to aid an analyst in formulating hypotheses to explain complex data relationships.

Model validation efforts applied to complicated systems are generally carried out by investigating the more manageable subsystems of the total model. This subsystem validation is then extrapolated through experience to include the entire model. While this method may be satisfactory, it is difficult to combine the results of the piecewise validations into a meaningful (quantitative) statement answering the question, "How valid is the complete model?" The following results show one example of how PROBE can be used to help the analyst answer that question.

This example involves using pattern recognition techniques to identify problem areas in the computer simulation used for modeling rocket trajectories. Before a rocket is flown, a computer simulation is used to generate what is called a preflight trajectory. After the rocket is actually flown, a postflight trajectory simulation (which is the best estimate of the actual trajectory) is generated using all applicable data and telemetry measurements from the test. An important question is "Are there systematic errors in the computer simulation of the preflight trajectory which show up in the comparison between preflight and postflight trajectories?" (From past experience, there is reasonable confidence in the belief that there are no systematic errors in the postflight estimation procedure) The method of answering this question will be called model validation.

In model validation the difference between the preflight and the postflight trajectory parameters will be called the deltas. The approach to model validation then becomes a matter of determining if there is some systematic relationship between the various preflight trajectories and the deltas. For instance, it could be that in high lofted trajectories the preflight computer simulation might overestimate the simulated cutoff velocity when compared with the actual cutoff velocity.

The particular example presented here involves 33 separate trajectories, each with six variables. These variables are: 1) altitude; 2) downrange distance; 3) magnitude of velocity; 4) Mach number; 5) dynamic pressure; and 6) burn time. The preflight values for the variables are calculated by a computer simulation and correspond to the estimated values near the end of first stage. The postflight values are obtained by direct measurement from the actual rocket test. The data to be analyzed consists of the 33 separate trajectories with 12 parameters each —6 preflight parameters and 6 delta parameters.

Because in this situation there is no absolute determination of what constitutes success or failure, the initial steps followed here may differ from those used in manufacturing process analysis. The first step in the screening process involves examining the mean value and standard deviation of each of the six delta parameters. A large value of the mean in comparison with the standard deviation could indicate a systematic bias in that particular parameter. A large value of the standard deviation could also indicate problems in a parameter. For this example, the mean values of the deltas

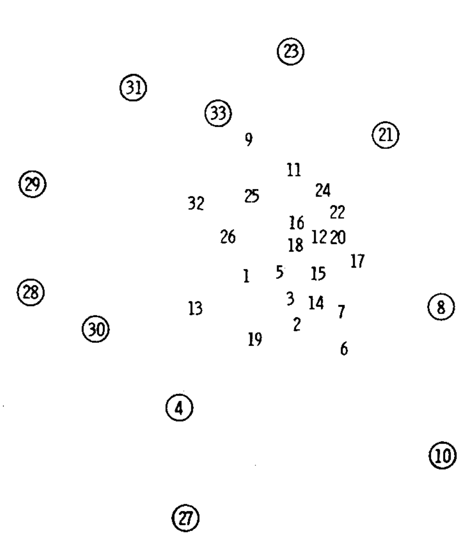

Fig. 1 Representation of trajectory deltas.

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were all significantly smaller than the standard deviations, and the standard deviations also were relatively small. Hence, there were no obvious discrepancies in the model which showed up on the first screening step.

In the second step of the screening process, PROBE was used to calculate a covariance matrix of correlation coefficients for the twelve parameters. The results indicated a high correlation between five preflight parameters. Lower altitude was correlated with higher velocity, higher Mach number, and higher dynamic pressure. The preflight first stage burn time was relatively uncorrelated with other preflight parameters. Also, the delta parameters were relatively uncorrelated with one another and with the preflight parameters. If there were a high correlation between preflight parameters and delta parameters, it would indicate systematic errors, but since this did not occur the model passed this second step successfully.

The third step involves a pictorial examination of the delta parameters for each trajectory with the purpose of discovering relationships which could have been missed in the statistical analyses. Figure 1 shows a display in which the numbers 1 to 33 correspond to the 33 individual trajectories. The six-dimensional space corresponding to six delta parameters is mapped onto a two-dimensional space in order to obtain the two-dimensional representation as shown in the figure. The data in multidimensional space is represented in the two-dimensional pictorial representation by either standard projection or else by a nonlinear mapping. The nonlinear mapping tries to maintain in the two-dimensional representation, the relative distances in the multidimensional space. The distances have been normalized so that the standard deviation of each delta parameter is equal to unity. A cursory examination of the figure shows no systematic clustering of the trajectory points, so the model passes this third test successfully.

For the fourth test the points whiih are circled are those which have relatively large combined errors (in the original six-dimensional space). The question arises: "Is there some characteristic of the model (showing up in the preflight trajectories) which might give rise to relatively large combined errors?" To answer this question, a display similar to Fig. 1 was made, in which the numbers 1 to 33 correspond to the same 33 individual trajectories, but the points in two-dimensional space represent the trajectories as characterized by the six preflight parameters (rather than the six delta parameters shown in Fig. 1).

In summarizing this particular example, a general observation was made that rocket trajectories with lower flight-path angles (and related characteristics of low altitude, high velocity, etc.) tend to have larger discrepancies between the preflight and postflight parameters. Follow-up investigations of the trajectory model subsystems (aerodynamics, propulsion, mass properties, models, etc.) are indicated. In general, the trajectory model validation effort accomplished with the PROBE techniques has been successful to date. While past efforts have not led to the discovery of any gross model errors requiring changes, they have provided the analysts with a quantitative review of total model performance which heretofore has been lacking.

Two other applications will be mentioned here briefly, comparative data analysis and manufacturing process analysis. During flight testing of rocket motors, massive amounts of telemetry data are obtained for the purpose of both analyzing the vehicle performance and determining reasons for malfunctions should they occur. After several years and many tests, it is not hard to imagine the formidable amount of information collected, and the difficulties which arise in attempting to relate results from one test to another. The need for techniques to provide some type of rapid data scanning is again obvious, if any serious attempt is to be made at comparative analyses. The two-dimensional pictorial display provides a means by which multidimensional data can be examined quickly to discover outliers or discrepancies.

In the manufacturing of hardware for rockets, as in many sophisticated manufacturing processes, a large number of materials and procedures combine to form the end product. Throughout the whole process, materials and components are tested, retested, and results documented. For the problem considered here, an attempt is made to sort manufactured items into two groups—those that had success in testing and those that failed in testing. The purpose of the Pattern Recognition techniques is to see if there is some relation between the measurements made during the manufacturing process and the results of the destructive testing made later.

The results of our experience with pattern recognition techniques can be summarized as follows: in artifically constructed problems, the correct answers are known, and it is a simple task to determine the efficacy of a particular solution technique. In a real problem, such as in the examples considered here, the correct answer is not known at the time a solution is desired. In fact, the correct answer might never be known, or there might be a considerable period of time before the success of a proposed solution can be evaluated. Hence, in real problems, the generation of viable hypotheses is a critical requirement. PROBE has been successful as a technique to generate hypotheses in contrast to the classical statistical methods which are used primarily for verification purposes. In addition to this use, however, several other practical benefits have emerged from use of PROBE techniques. 1) They provide a credibility check on existing models and investigation. 2) They force investigators to organize and automate proper data bases. 3) Technicians gathering data become less of a hazard because bad data is made more visible. 4) They provide a quick and inexpensive means of surveying existing data bases. 5) They allow qualitative information to enter the analysis through visual analysis of data groupings. 6) They allow investigations to look at more variables, hence second-order effects are not left out for convenience. 7) They produce statistical information in a form directly related to the discovered patterns. 8) Finally, they allow the analyst time to analyze, and not just collect and manipulate data.

Prior to our application of PROBE to the described problems, reasonable progress was being made. However, we feel that PROBE and similar techniques will add immeasurably to the capability of existing data handling and analysis techniques.