A PERFORMANCE TRACKING METHODOLOGY AND DECISION SUPPORT MODEL

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Abstract - This paper presents a methodology to detect performance degradation with a certain degree of confidence, and a decision support model to help engineers and technicians to solve ongoing diagnostic and repair problems. The method is capable of detecting changes in performance trends when data captured at different times or ages during the system's active life, is compared to estimated performance limits. This paper applies the method to the specific case of aircraft avionic systems and their associated support equipment. The methodology is currently being developed and applied to existing aircraft avionic equipment and maintenance processes. The methodology explores the ability of statistical control process applications and expert systems based technologies to develop trend analyses data and provide performance degradation information to maintenance engineers, technicians, and managers. The paper will address specific data capture and component identification problems encountered in actual test data, and will discuss automated solutions for these problems. A complete architecture will be presented displaying the data capture process, data storage, statistical and expert system processing, and output information display. The solution includes the specific technology used to implement the process and output information samples based on actual test data.

INTRODUCTION

Any known system will fail or misbehave at some point. It is just a question of when. The effect of the failure or change in performance interferes in different degrees with missions that depend on that system. In critical missions a system failure can lead to catastrophic consequences. Significant changes in the performance of equipment may occur as a result of aging and other factors within weapon systems and their associated support equipment. Current methods do not allow for the effects of these factors in the determination of equipment performance tolerances or test limits, resulting in apparent and actual decreases in equipment readiness and test program precision. The overall cost of a failure or malfunction, measured in any standard, is always higher than the preventive action. Therefore, system users are interested in knowing when a system or part is about to fail in order to take preemptive actions.

The methodology presented in this paper is designed to comply with a variety of architectures and processes to collect, parse, store, and process both test and failure data, and distribute failure prediction information. The SYSTEM CONCEPT section describes the overall system concept. The SPC ANALYSIS section describes how trends are detected to support the failure prediction. The WEIBULL ANALYSIS section describes how failures parameters are computed and integrated with the SPC results. The EXPERT SYSTEM describes how the SPC trends and the Weibull analysis are integrated to populate the knowledge base and generate end-user advisories. Actual results are presented in section CURRENT RESULTS. The latest conclusions about the research are presented in the CONCLUSIONS sections.

Although the general concepts and architectures are discussed and presented, this paper will concentrate on the data analysis and expert systems methodologies used to predict component failures. These methodologies are currently being developed to support the USAF F-16 aircraft. All numerical results presented in this paper are unclassified F-16 actual data.

SYSTEM CONCEPT

Data Sources and Data Collection

With the coverage provided by current communications technology, data can virtually be collected from anywhere, provided that there is a link to the data originator. Secure communications can be achieved through encrypted codification and other mature and well-known technologies. Data links include the Internet, LAN, WAN, phone, and wireless communications. Once the connectivity between the data originator and the processing center is established, data can be collected and programmed by an automated process. Locations (domains, folders, instruments, etc.), time, and collection rules can be scheduled to accommodate a fully automated data collection process.

In our specific application for the F-16 avionics, test data is provided by ATE connected to a LAN. Parts tested by the ATE machines are separated in three types: 1) F-16 aircraft parts, 2) ATE (test station) internal parts, and 3) hardware interfaces. Aircraft parts are shop replaceable units (SRU) detected as defective by flightline maintenance personnel. Test station parts are station components tested during self-test routines. Hardware interfaces are sub-systems used to interface the aircraft parts and the ATE. The test routines are controlled by software (written in ATLAS language) running on the ATE. In all three cases the test software outputs test parameters, such as part identification and test results, from the ATE to a PC emulating terminal via serial port. The ASCII format information transmitted from the ATE to the PC is captured to files located in the local hard-drive. The ASCII files are then collected to a central server, parsed, and stored in a database.

Data Storage

The database is intended to store all raw test data and results from statistical analysis. Failure data is provided by a remote system designed to collect and store depot "work documents". These documents contain information provided by the maintenance technicians regarding replacement parts and other repair information. Both test data and repair data are applied to the method described in this paper. The system is compatible with two database formats: Microsoft (MS) Access, and MS SQL Server. The selection of these formats is based on maintainability and supportability requirements by the customer's network administrators. The MS-Access format is used during the development and is very portable. The MS-SQL Server will be used in the final production version. The compatibility between the two formats turns migration an easy task. The implementation is not limited to the MS formats. The Open Database Connectivity (ODBC) used in the development turns the interfacing with any ODBC compliant database.

Data Analysis

Statistical control process (SPC) tools processes and analyzes the raw test data, and the Weibull analysis tools processes repair (failure) data.

Statistical Process Control

Statistical control processes (SPC) are analysis tools used to check rules against data points. The rules basically verify if any, and in positive case how many, data points fall within a range of values. The validation range is defined to characterize events such as out-of-limits data points, data points in the 3σ zone, N out of M consecutively increasing (or decreasing) data points, decreasing averages, etc. Individual events and group of events, associated with existing knowledge about the system's performance, will lead to performance degradation detection. Regression analysis applied to the data points can also lead to failure prediction by comparing trends and acceptable tolerances or limit values.

Weibull Failure Analysis

The Weibull analysis is traditionally used to analyze component or system failures. The traditional Weibull parameters are the shape parameter, the characteristic life, the initial date, and the mean-time-to-failure (MTTF). These parameters are used to compute reliability, probability distribution function, risk analysis, and other statistical information. The Weibull distribution can be separated in the 2-parameter and the 3-parameter distributions. Alternatives to the Weibull distribution are the Normal and the Log-Normal distributions. The Weibull parameters can be determined by regression or by maximum likelihood methods. The likelihood method provides the confidence levels for the estimates. The goodness-of-fit, based on the r^2 coefficient, compared to the critical correlation coefficient, provides a criteria to select the best data distribution (Weibull 2-parameter, Weibull 3-parameter, or Log-Normal). Failure data is represented by age at the failure. For the F-16 case, the exact age of failure is not accurately tracked. The best age information is based on the repair date logged in the shop work documents. The repair date can be days, and sometimes weeks, off the actual failure date. This data uncertainty leads to low confidence levels and uncertainties in the estimated Weibull analysis results.

Expert Systems

(include a brief description on the Expert System concepts and uses, based on other applications – details will be mentioned in the following sections)

Output Information Display

Decision support information is released to end-users as technical advisories. Information is displayed from the lowest level of complexity to the most detailed information available, upon request by the user. The information is accessed directly from the database with minimal client side processing.

In the F-16 avionics case, information is displayed to engineers using LabVIEW virtual instrument (VI) modules. These modules are also available via browser. The information is also distributed via web-based user interface.

THE SPC ANALYSIS

The statistical process control (SPC) tools consist of a series of rules that are checked against a set of data points. The rules are designed to detect events such as data points outside upper or lower limits. This basic rule simply detects if output signals are out of tolerance, possibly indicating a component failure. Other rules anticipate the out-of-limits event by checking data points in the one, two or three-sigma zones (sigma = standard deviation). Yet other rules detect N out of M consecutive points within a certain zone of values that evidence mal-functioning. A certain combination of infringed rules may indicate that a component is close to fail. Despite the fact that the SPC rule checkers are standard procedures, the failure analysis (or simply ill-behaviored), the combination of checks and infringed rules that provide a failure diagnostic is particular to a specific system or component. The problem is turned complex when multiple-failure modes are present.

For the particular case of the F-16 avionics system the following SPC rules were checked:

number of data points above (or below) the upper (or lower) confidence limit,

number of data points above (or below) the upper (or lower) limits,

number of points in the 1σ, 2σ, and 3σ zones,

N out of M consecutive points in the 1σ, 2σ, and 3σ zones,

N out of M increasing (or decreasing) values,

WEIBULL ANALYSIS

The Weibull analysis tools consist of algorithms that analyze failure data provided by the repair database. A minimum of three failure data points is necessary to perform the Weibull analysis. The basic information that is output by the method is the mean-time-to-failure (MTTF). This information provides the time units remained until the next failure with a certain confidence level. The confidence level is affected mainly by the accuracy of the failure age (date and time of failure). The more accurate is the age, the more accurate the failure can be predicted. The goodness-of-fit is represented by the $\mathbf{r}^2$ correlation coefficient. This coefficient can be used to select the 'best fit' distribution. The correlation coefficient is compared to the 'critical correlation coefficient' to identify which statistical distribution best fits the data points. The following distributions are available: two-parameter Weibull, three-parameter Weibull, and log-normal distributions. Weibull charts plot age of failure against median rank. Auth and Bernard methods calculate the median rank.

For the F-16 case, the Weibull analysis is being applied to avionic parts. A particular avionic part number (P/N) /serial number (S/N) was selected to validate the methodology. This particular P/N-S/N system has 15 known failures and four different known failure modes. The two most frequent failure modes have eight and four occurrences respectively. The other two failure modes have two and one occurrences each. The first two modes will be used in a 'reverse engineering' process to validate the software. All failures are plotted in a Weibull chart and presented in figure 1. This figure presents all failures for the specific P/N-S/N combination. The failure dates are represented by the actual repair dates, thus introducing some uncertainty in the failure ages. All components that were repaired (replacements and or adjustments) are known.

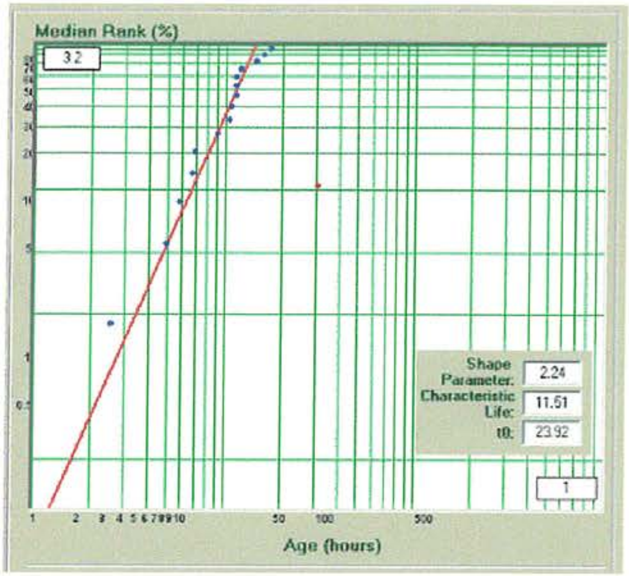

Figure 1 – A Weibull plot with multiple failure data points.

Figure 1 clearly shows that the failure data points belong to different failure modes (at least three break-lines). The automatic detection of the 'best fit' suggested the three-parameter Weibull distribution. The lack of initial knowledge of the failure modes does not make the task of grouping the data points an easy one. In our case, the anticipated knowledge of the failures helped in determining the data point groups. Figures 2 and 3 present the Weibull charts for the data points grouped by failure modes.

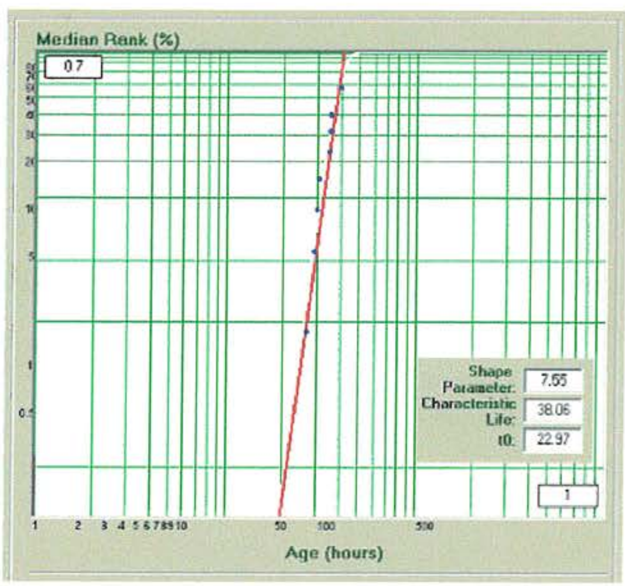

Figure 2 – Weibull chart for failure mode no.1

Figure 2 presents the Weibull charts for the data points related to the failures that required the replacement of 'P1' component. The characteristic life is determined to be 38.06 days. In practice, the failures occurred every

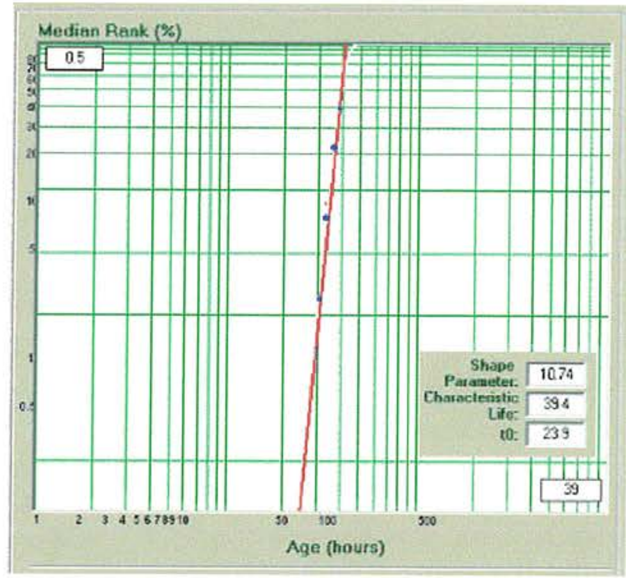

Figure 3 – Weibull chart for failure mode no.2

Figure 3 presents the Weibull charts for the data points related to the failures that required the replacement of the 'handle'.

The Weibull algorithms are classical and presented in many references [2], [3].

EXPERT SYSTEM

(this section will describe the specific ES that will be used to integrate all data and information and provide advisories to end-users – include the knowledge base)

CURRENT RESULTS

The system currently accumulated more than 200,000 test data points for about 40 different parts (aircraft and station) and 100+ test types. 40,000+ records representing over 400 part numbers represent repair data. Figure 4 presents test data points acquired in a three-month period for a specific station P/N. The data points correspond to measurements on a 5VDC power supply. In this case a trend is clearly identified. By immediate visual inspection and liner regression, a drift of -0.05 volts/day is detected. With a lower acceptable limit of 4.95 volts, and at the current rate, the threshold should be reached in 100 days. At this time either part replacement or adjustment should be required. Preventive maintenance can be anticipated to avoid reaching the failure point. The SPC tool applies the rule check procedures and provides advisories as the measurements enter the 1σ, 2σ, or 3σ zones. The interpretation of the discontinuities in the signal requires more deep analysis.

Factors such as room temperature and humidity are known to affect the measurements. However these factors are not automatically captured. Small steps are also due to adjustments. The automated process continuously monitors the P/N and advisories are posted to engineers and technicians informing about potential failures and degraded performance.

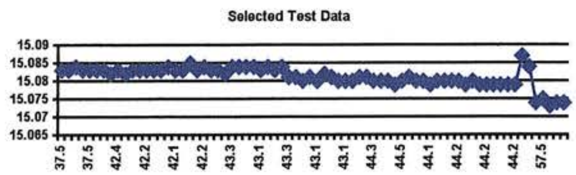

Figure 4. Test data and trend analysis on a 5VDC power supply.

CONCLUSIONS

The decision support system (DSS) presented is capable of detecting performance degradation. The already achieved results show evidence that failures can be forecasted with a certain degree of confidence. The accuracy of the information is dependent on the accuracy of the "age" of the data. The maintenance personnel do not accurately provide dates. Trend analysis is also affected by the lack of data such as serial numbers. The DSS is also capable of providing failure advisories for no-failure parts.

POTENTIAL APPLICATIONS

The DSS is capable of supporting a large number of processes where performance must be monitored and degradation and failure is critical. The aerospace industry has benefited from the failure analysis in the propulsion area. Weibull is intensively applied to predict failures in aeronautical engines. The Weibull analysis tools presented in this work are available for direct use in areas that require a methodology to determine failure analysis. The automotive industry is increasing its on-board diagnostics capability. Test emission methods and engine maintenance procedures can be improved by more advanced sensors, data capture processes, data analysis, and diagnostic procedure. Lipke and Vaughn presented in their reference [3] how SPC can be applied to management. Their paper specifically deals with the case of software development management tools. Financial health, project management, workload and labor, and process improvement can be monitored and measured using SPC tools as the ones presented in this work. Some other areas of potential use are: monitoring and detection of performance degradation in satellite navigation systems, such as the GPS/GLONASS, medical diagnostics and health monitoring systems.

SPONSOR

The US Small Business Innovative Research (SBIR) program under project AF98-262 sponsors this research.

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