Intelligent Debris Analyzer
A New Tool For Monitoring Lubrication Machines

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Abstract: Critical aircraft and marine components such as turbine engines and gear boxes usually require health monitoring techniques to periodically assess their condition. Debris entrapped in their oil filters contains a vast amount of untapped information. If interpreted properly, this information can be interpreted and applied for monitoring the overall machine condition and can be used to make important and relevant maintenance recommendations. Standard oil analysis methods do not generate the results required to make similar recommendations for the operation of systems with fine filtration units. Furthermore, current manual methods for filter debris analysis rely on expert knowledge and expertise and are time-consuming, expensive and inconsistent. They are, therefore, not really exportable from the laboratory to the shop floor. This paper describes a novel Intelligent Debris Analyzer (IDA) system for detection of impending failures and diagnosis of wear trending. IDA is a hybrid artificial intelligence system incorporating digital image processing, pattern recognition and an expert system. This new system automatically evaluates the debris image, draws an expert conclusion on wear conditions and recommends maintenance actions.

Key Words: Filter debris analysis, image processing, pattern recognition, expert system, artificial intelligence and machine condition assessment.

Background: Traditional methods of determining wear condition of oil-wetted machinery include the use of oil pressure and temperature indicators, magnetic electric chip detectors, optical particle counters, spectrometric oil analysis (SOA) and ferrography. These approaches are very successful in predicting failures when a number of specific criteria are met:

- The small debris particle size for which spectrometric oil methods are sensitive is indicative of the total debris generated by the equipment.
- The debris left in the filtered oil is sufficient to be useful diagnostically.
- The total amount of debris generated is indicative of the machinery condition.

In the past, when coarse filtration systems were used, all of these conditions were met. In today's fine filtration systems (less than 10 microns), most of the large particles with one or more of the above criteria are not met since all debris greater than the pore size of the filter is trapped. Consequently, both ferrography and SOA are deemed unusable for determining the wear condition of these systems. Furthermore, certain types of failures, such as gear failures, will produce particles too large to be detected by most conventional methods. In addition, a significant amount of experimental data on operating systems suggests that the amount of debris being generated is not the sole indication of wear condition, and that size, and, to a lesser degree, conformation of the particles is as important as quantity.

Introduction: This research and development project was based on work that took place at the Canadian Defence Research Establishment Pacific in the early 1990's. The approach used image analysis techniques combined with innovative artificial intelligence methods to lead to an automated monitoring technology. The project included four basic areas of research: Post-cleaning Debris Separation, Digitization Technology, Imaging and Interpretation using Pattern Recognition, and Neural Networks Methods.

With this condition monitoring technique, it is the assessment of information contained in the filter that is important. To remove the debris in the filter, an ultrasonic cleaning bath in a varsol solution was used. Once the debris was removed, which usually took around thirty minutes, the varsol solution contained most of the debris that had been captured by the filter. To assist in the evaluation process, magnetic segregation was performed prior to imaging the results. The system performed analysis as per the logical diagram shown in Figure 1.

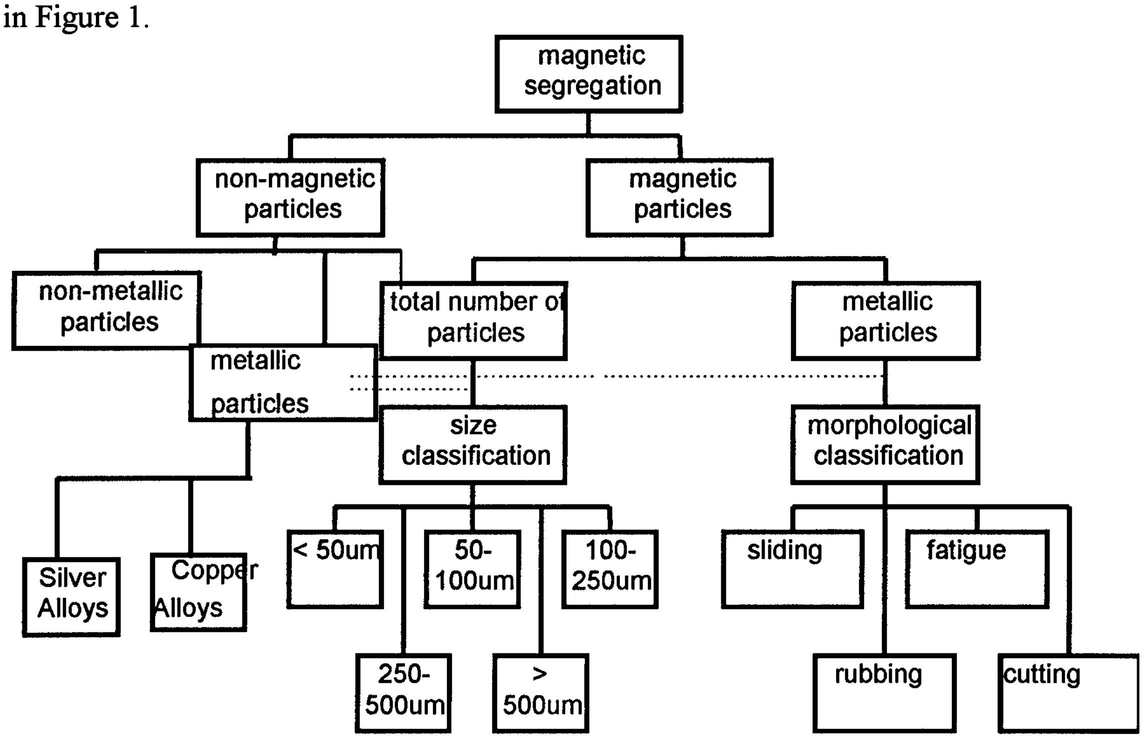

Figure 1. IDA Logic Decision Tree

As shown in Figure 1, considerable information was extracted from the system. This information included particle size distributions, % area covered, wear classes and trend.

All of this information was available for both the magnetic and non-magnetic particles through digitizing, imaging and interpreting the filter debris. The IDA platform used to perform this analysis consisted of a metallurgical microscope, a XY-motorized stage and controller, optical lenses, a color camera, a personal computer and a graphic frame grabber. A schematic representation of the digitizing platform is shown in Figure 2.

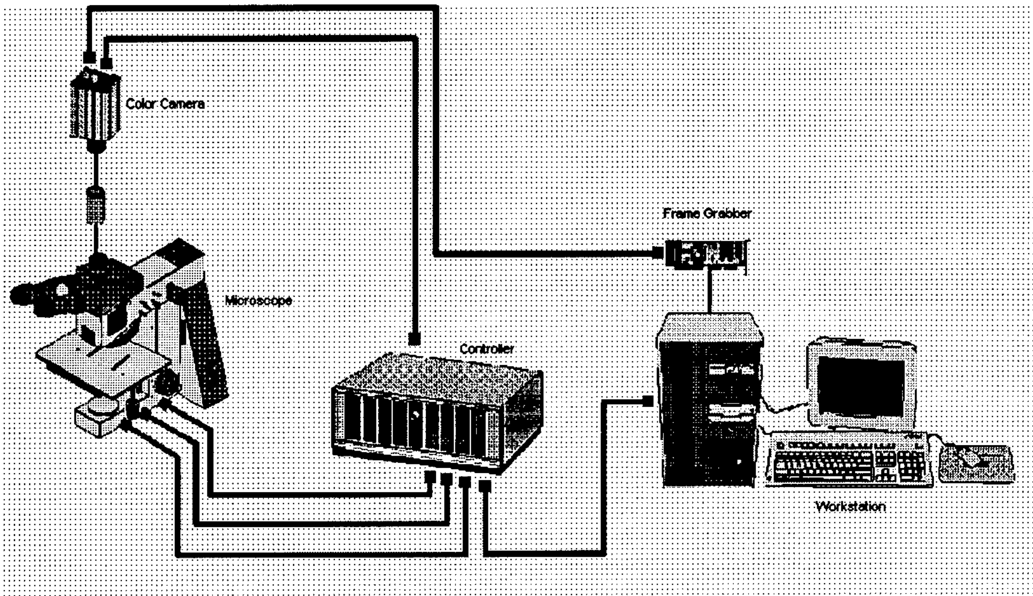

Figure 2. The IDA Platform

Description: The imaging process began by stitching images together to obtain a "mosaic" image. Adaptive software adjustment of the contrast and colour characteristics of the captured images was performed to ensure matching of adjacent images. The process of image scanning and stitching is illustrated in Figure 3.

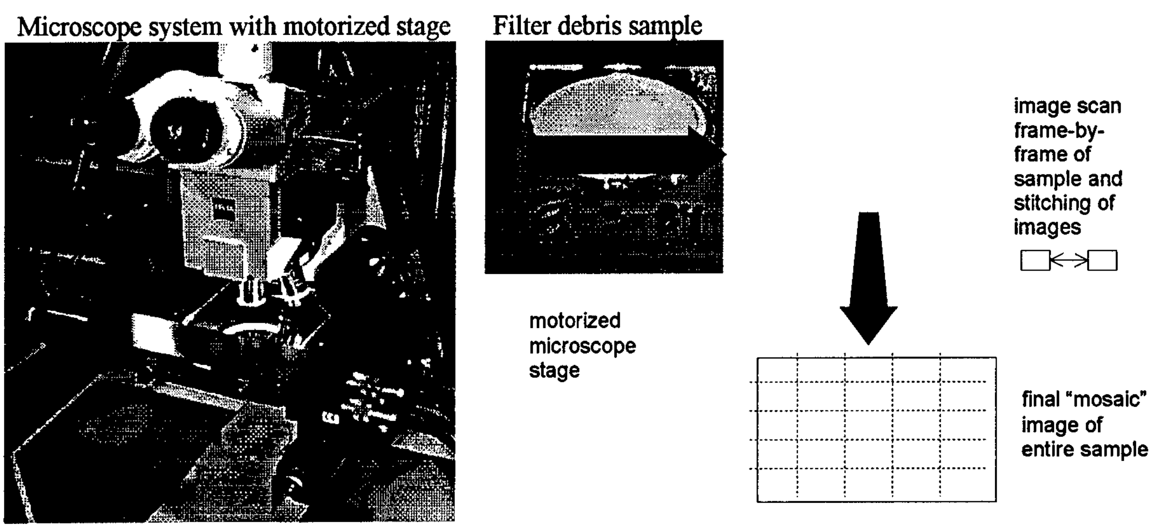

Figure 3- The Mosaic Image

Once an image mosaic was obtained, the particles in the image were segmented for particle identification. To perform this task, an edge-detection filter and auto-thresholding algorithm were developed and incorporated. Figure 4 shows the results of the segmentation on typical metallic debris.

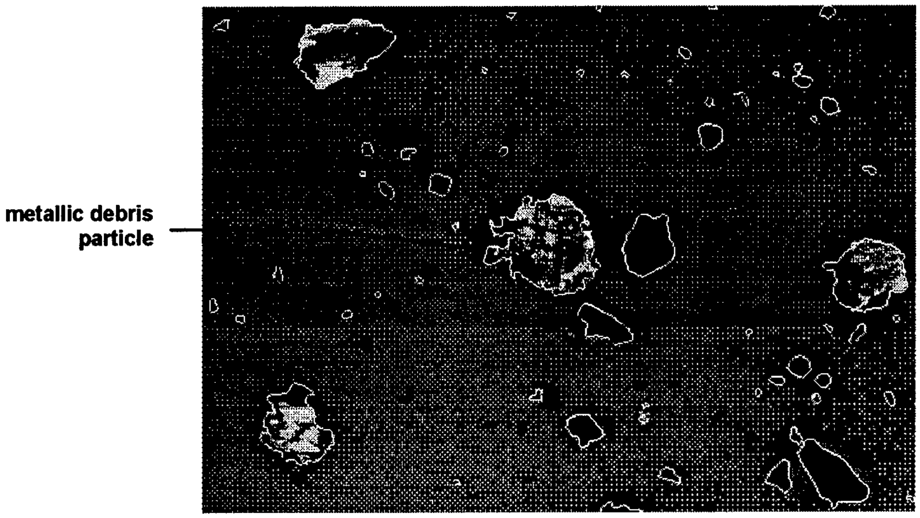

Figure 4. Debris Segmentation

With the objects properly segmented, labeling routines were called into operation to aid in the analysis of the detected objects. Functions were used to classify the detected object by class size. To enhance the quality of the mosaic image, auto-focus, zoom and color characteristics were included. A number of digital filters were applied: lowpass, auto-threshold, sobel edge detecting, binary, thinning, and morphological closing filters. Each particle was segmented from the filter patch background and saved as an individual image file. Then, the particle image was fitted to an ellipse and the size of the particle was extracted by calculating the major axis of its associated ellipse. Particle size classification and number counting were processed automatically for both the metallic and non-metallic particles. As well as using thresholding techniques, trending was used to recommend a maintenance action.

The system provided an evaluation of the machine condition anomalies and its severity based on size distribution counts and trends. In addition, a morphological assessment of the debris was also included. Using pattern recognition techniques and the morphological features, each particle was segregated by its wear type. In addition, texture features and color features were weighted to distinguish between metallic particles and non metallic particles. A database, embedded into the system, stores the classification results. The overall result was a system that provided a quantitative assessment of the extent and type of debris by classifying debris as cutting, fatigue, sliding and rubbing wear. The wear type condition was used to provide additional recommended maintenance actions. To obtain this assessment, a number of spatial and frequency-based features were extracted from the debris images. Pattern recognition and neural networks were used to develop a classifier. From expert knowledge, a set of deterministic rules adapted to specific components was used to identify the cause of an abnormal problem.

The current result can easily be saved or retrieved via the database engine to perform trending analysis. The expert knowledge was collected from lubrication engineers and delivered to the expert system at the very onset of the consultation session. The forward chaining algorithm, serving as a reference engine, analyzed the classification and trending results. It provided additional tools to the system to diagnose wear condition and provide maintenance recommendations. The process is shown schematically in Figure 5.

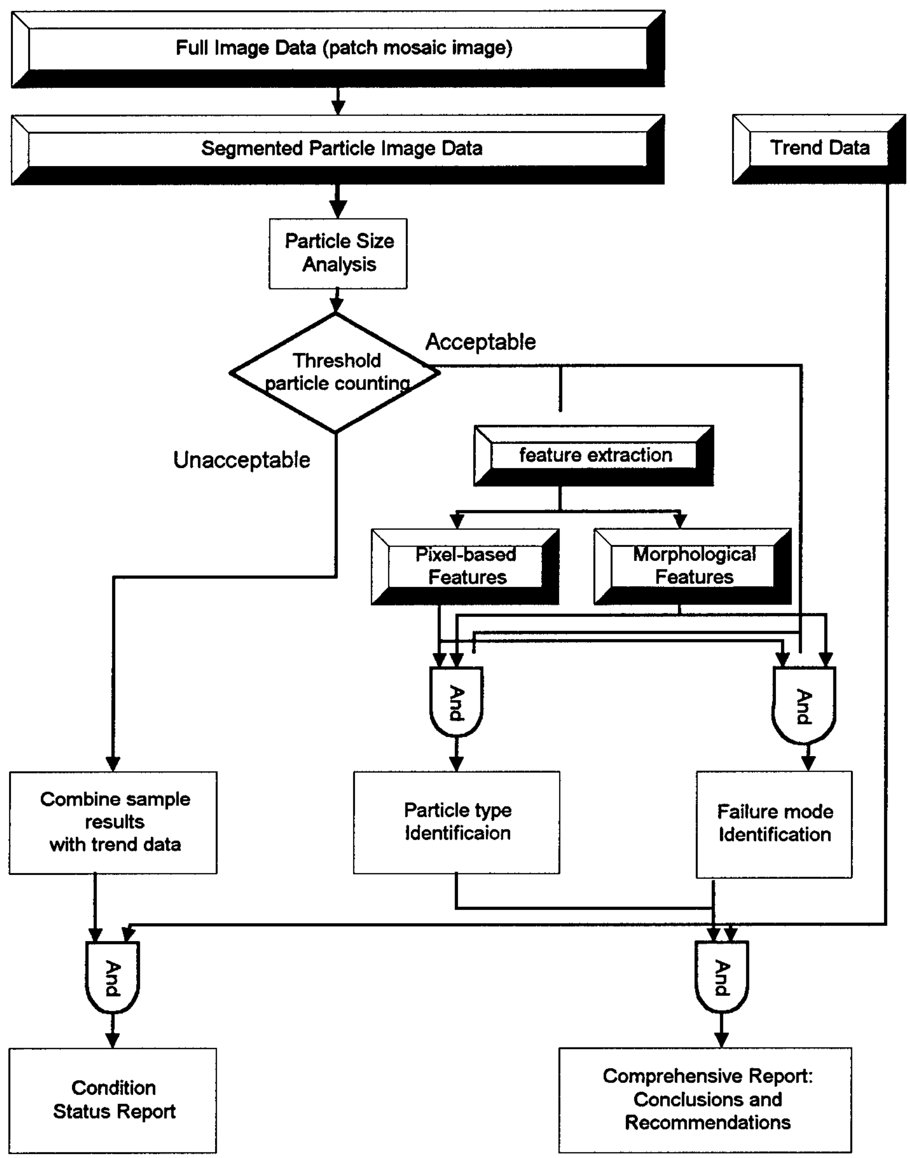

Figure 5- IDA Decision Process

Conclusion. An image analysis workstation has been developed and incorporated into an automated system for diagnosing and tracking the condition of oil-wetted machinery. The acquisition system includes a metallurgical microscope, a servo motor stage and its controller, a digital camera, an image grabber board and a PC computer. Digital image processing techniques automatically enhance, segment and count debris particles contained in oil filters. Debris is classified using morphological features into diagnostic categories such as rubbing, cutting, fatigue and sliding wear. A database embedded into the system performs trending analysis. A deterministic expert system used as a reference engine, analyzes the classification and trending results.

IDA is a powerful monitoring technique that offers a new means to diagnose wear condition and provide maintenance recommendations for components of oil-wetted machinery. It has the capability of being used with both standard and fine-filtration systems and will be available commercially in the near future.