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Visual Anomaly Detection via Soft Computing: A Prototype Application at NASA

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Abstract

A visual system prototype that detects anomalies or defects in real time under normal lighting operating conditions was built for NASA at the Kennedy Space Center (KSC). The system prototype is basically a learning machine that integrates the three elements of soft computing, Fuzzy Logic (FL), Artificial Neural Network (ANN), and Genetic Algorithm (GA) schemes to process the image, run the learning process, and finally detect the anomalies or defects. The system acquires the image, performs segmentation to separate the object being tested from the background, preprocesses the image using fuzzy reasoning, performs the final segmentation using fuzzy reasoning techniques to retrieve regions with potential anomalies or defects, and finally retrieves them using a learning model built via artificial neural network optimized using genetic algorithm techniques.

This prototype system was originally tested on the detection of anomaly or defects at slidewires used in the emergency egress system at the NASA Space Shuttle launch pad at KSC. The prototype system successfully detected all defects classified under "loose strand". The imaging technologies based on fuzzy reasoning approach and created to preprocess the images have received NASA Space Awards and are currently being filed for patents by NASA; companies from different fields including security, medical, text digitalization and aerospace, are currently in the process of licensing these technologies from NASA.

1 System Description

Fuzzy logic provides a powerful framework for knowledge representation and overcomes uncertainty and vagueness typically found on image analysis. Neural network provides learning capabilities, and generic network approach leads to robust learning results. The system may run on either a regular PC under Windows NT or an embedded version for portability.

The system acquires the images from a video camera via either an analog or digital image grabber. Using fuzzy reasoning, the image undergoes preprocessing that includes primary segmentation, object extraction, enhancement, filtering, and edginess detection. An adaptive fuzzy threshold binaries the preprocessed image, and a selective blob detector picks image regions with high edginess activity. The system computes morphological, geometrical, and fuzzy edginess grading values for each region and uses them as inputs of the learning feature via GA-ANN schemes. A schematic of the system is shown in figure 1.

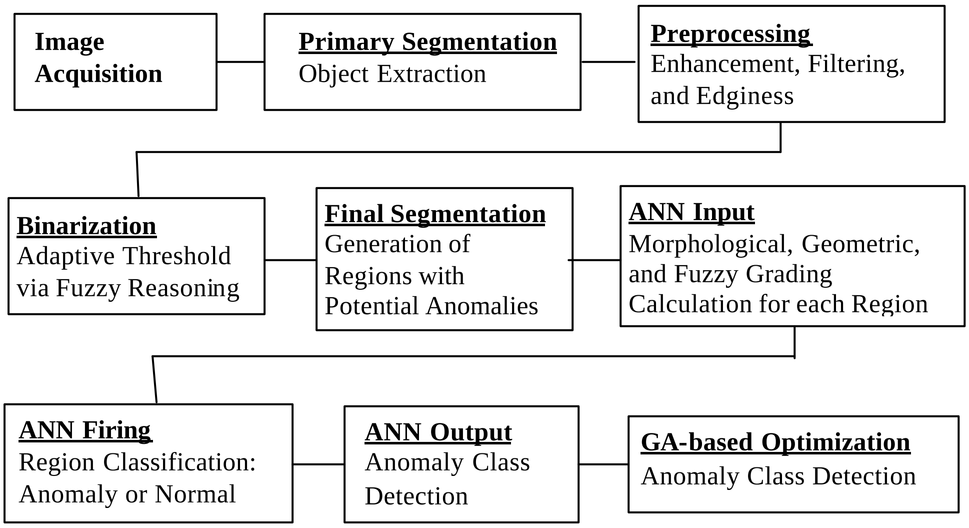

Figure 1. Schematic of the intelligent visual anomaly detection system.

The software development tools used in the implementation of this system include Microsoft Visual C++, Microsoft Foundation Class (MFC), and two commercial software packages: Wit image analysis software from Logical Vision and NeuroShell Classifier from Ward Systems.

Wit software allows the developer to build customized image operators in C and a front end to make the application friendly and transparent to the end user. We designed and built most of the image operators, including those needed to perform image preprocessing, via fuzzy reasoning. The ANN scheme is based on Probabilistic Neural Nets (PNN) but is formulated a little differently, based on GA as opposed to a network structure.

PNN's instantly train, unlike back propagation. In fact, they do not really train at all; they memorize, and the only freedom they have to generalize is to vary the smoothing factors. So the approach used in NeuroShell memorizes all of the patterns in the training set. Then it begins generating genetic individuals with GA. Each individual is a set of smoothing factors, which, when applied to PNN, makes a complete net. That net is tested against the test set, and the results become the GA fitness function. The GA generates the smoothing factors that perform the best against the test set, but all nets thus generated by the GA are trained on the training set (memorized). NeuroShell Classifier contains this new GA-PNN network paradigm. NeuroShell Classifier is spawned via DLL functions to perform training and firing of the GA-PNN classification net.

On the end-user side, all the features involved in the system are completely transparent. The end software product offers a friendly and easy-to-use template (all built via MFC) with a menu to select and perform training, analysis, and detection. The system has two end products, the development software package that includes all the system features and the run-time package designed to just run the anomaly detection system in the field.

2 Fuzzy Reasoning and ANN Integration

Visual inspection faces many levels of uncertainty inserted into the data by a variety of processes from the original sensor through several levels of interpretation. The integration of the three constituents of soft computing – FL, ANN, and GA – is used to manage these levels of uncertainty. Soft computing differs from conventional (hard) computing in that, unlike hard computing, it is tolerant of imprecision, uncertainty, and partial truth. In effect, the role model for soft computing is the human mind.

Fuzzy reasoning and ANN lead to a symbiotic relationship in which fuzzy systems provide a powerful framework for knowledge representation, while ANN provides learning capabilities and exceptional suitability for computationally efficient hardware implementation. Generating optimal smoothing factors via GA approach significantly enhances the performance and robustness of the PNN.

3 Prototype Application

NASA built an inspection mechanism called Cable and Line Inspection Mechanism (CLIM) to provide a means of automated image acquisition of the fourteen 1000-foot slidewires used in the emergency egress system for the NASA Space Shuttle at KSC. CLIM eliminates the hazardous, manpower-intensive, and time-consuming methods previously required to manually maintain the emergency egress system at peak performance. The inspection of the emergency egress system using CLIM still requires having a person continuously watch cable images for more than 48 hours. Figure 1 shows astronauts training on the emergency egress system. Figure 2 shows astronauts drilling emergency egress at the Shuttle launch pad;

Figure 3 shows CLIM being tested at the Shuttle pad. Figure 4 shows a NASA flyer offering CLIM commercialization.

Figure 2. Astronauts drilling emergency egress at KSC Space Shuttle launch pad.

Figure 3. CLIM being tested at KSC Space Shuttle launch pad.

Figure 4. NASA flyer offering CLIM commercialization.

The intelligent anomaly detection system will be integrated to CLIM to completely eliminate the need for human intervention in detecting anomalies; the system will not only detect the anomaly, but also document it. Images acquired by CLIM are being used to test the intelligent real-time anomaly detection system. Figure 5 shows the front-end of the software built to run this anomaly detection system; two software sessions are clearly identified, the first one for training (off-line mode), the second for building the ANN-GA model, and the third one for running/firing (on-line) the training model to detect the anomalies. Figure 6 is a PC's screen snapshot showing an anomaly detected by the system. Figure 7 shows a sequence of three anomalies detected by the system from their respective original images acquired by CLIM. These three anomalies were classified under the same anomaly class (Loose slidewire strand) during the training session.

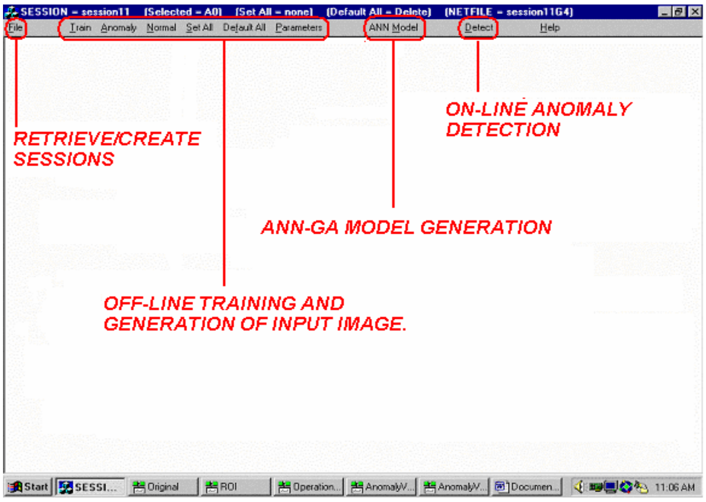

Figure 5. Main Menu holding all the options used to run the anomaly detection system.

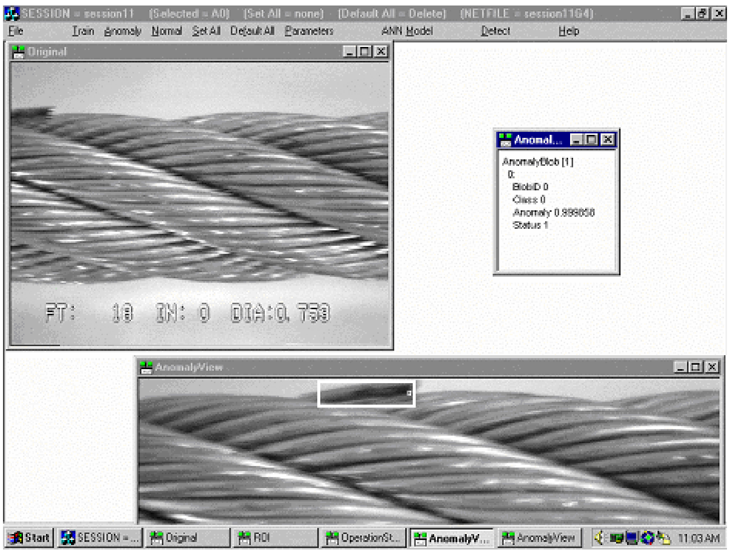

Figure 6. On-line anomaly detection performed by the system and displayed on the screen.

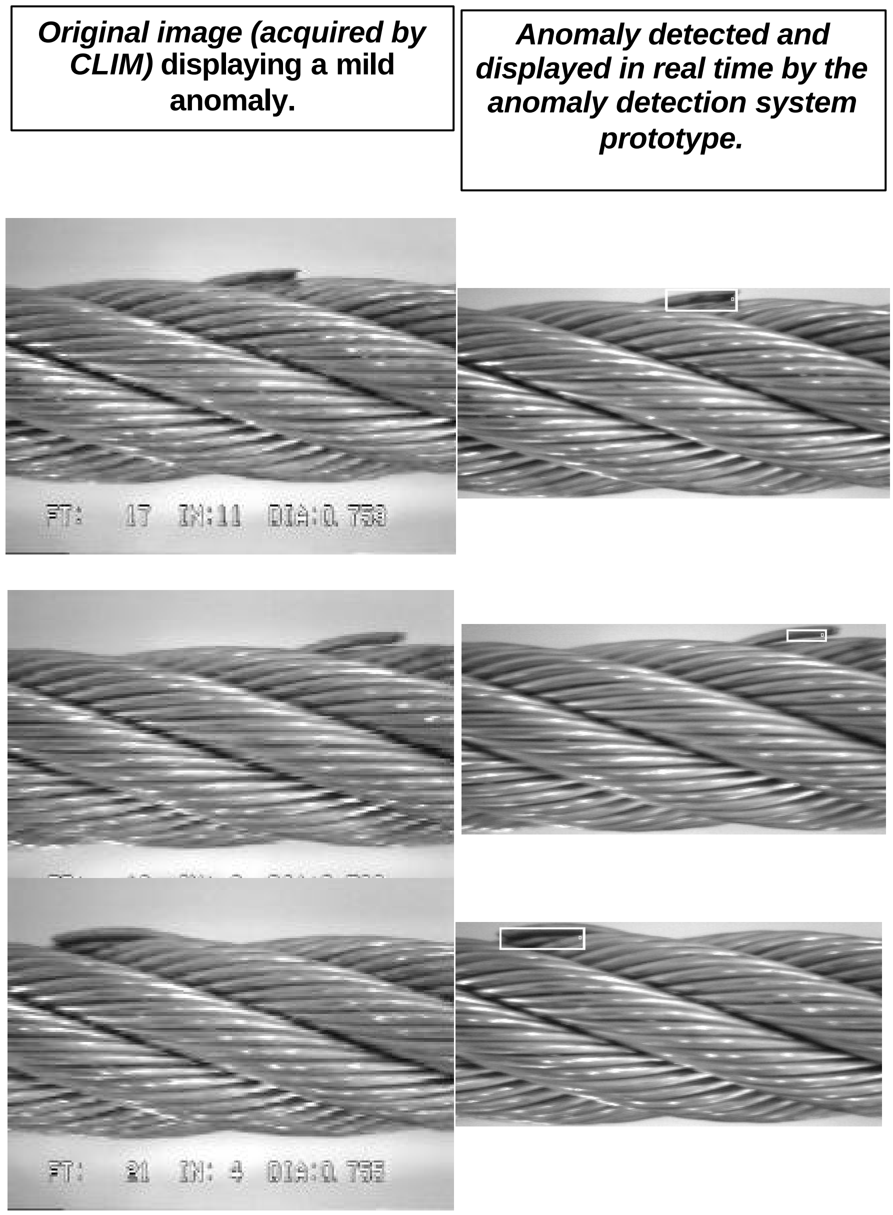

Figure 7. Three different anomalies detected and displayed under the same anomaly class.

The CLIM project, which has been designed to visually document the slide basket cables utilized by the astronauts to evacuate the NASA Shuttle launch pad in an emergency, is being used to test the system. Preliminary tests, using images recorded from a slide basket cable mounted in the laboratory, show promising results.

4 Conclusions

The potential applications of this anomaly detection system in an open environment are quite wide because there is no need for special lighting. One immediate application at KSC is the detection of anomalies of the NASA Space Shuttle Orbiter's radiator panels. Potential applications include automated visual inspection on spacecraft, ground, and flight equipment. The embedded portable version of this system might make the visual inspection of this type of equipment (including spacecraft fuselage) quite feasible in an open environment.

The fuzzy-reasoning-based imaging technologies built to preprocess the images in this anomaly detection prototype application have been successfully used in other advanced image analysis prototype applications, such as, detection and tracking of Foreign Object Debris (FOD) during the Space Shuttle liftoff and Space Shuttle Columbia accident investigation. These fuzzy-reasoning-based imaging technologies have received NASA Space Awards including a Board Action Award and are currently being filed for patents by NASA; they are being offered for commercialization through the Research Triangle Institute (RTI), an internationally recognized corporation in scientific research and technology development. Companies from different fields including security, medical, text digitalization and aerospace, are currently in the process of licensing these technologies from NASA.

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