

IMAGE ANALYSIS VIA FUZZY-REASONING APPROACH: PROTOTYPE APPLICATIONS AT NASA

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Abstract

A set of imaging techniques based on Fuzzy Reasoning (FR) approach was built for NASA at Kennedy Space Center (KSC) to perform complex real-time visual-related safety prototype tasks, such as detection and tracking of moving Foreign Objects Debris (FOD) during the NASA Space Shuttle liftoff and visual anomaly detection on slidewires used in the emergency egress system for Space Shuttle at the launch pad. The system has also proved its prospective in enhancing X-ray images used to screen hard-covered items leading to a better visualization. The system capability was used as well during the imaging analysis of the Space Shuttle Columbia accident.

These FR-based imaging techniques include novel proprietary adaptive image segmentation, image edge extraction, and image enhancement. Probabilistic Neural Network (PNN) scheme available from NeuroShell™ Classifier and optimized via Genetic Algorithm (GA) was also used along with this set of novel imaging techniques to add powerful learning and image classification capabilities.

Prototype applications built using these techniques 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.

Real-Time Detection and Tracking of Foreign Object Debris (FOD).

The motion detection is performed generally at the pixel level, at the edge level, or even at higher features levels. Existing features level algorithms for time-varying outdoor background require more computational efforts with respect to those working at the pixel level, but they provide more accurate information for higher system modules. This new motion detection system is not performed at the pixel level, provides accurate information, and supersedes the

robustness of the existing high-features-level algorithms requiring less computational time.

In the detection and tracking of FOD's during the NASA Space Shuttle liftoff, the prototype image analysis system uses segmentation via FR techniques to binarize the image and generate binary blobs in each image frame. Further blob analysis on consecutive image frames allows the system to determine which blobs are actually moving FOD's.

The image background during the liftoff is quite complex as moving objects that are not FOD's (ice flakes, fume clouds, external fuel line connections, etc.) constantly appear at the scene taped in black and white format. The prototype system has shown the capability of not only detecting actual FOD's observed in the tape images but also keeping close track of them (see figures 1 and 2). The trajectory of the debris is drawn in real time as the FOD is detected. Figure 3 shows the final trajectory of both detected FOD's in a bright background due to the accumulation of ice flakes (generated during the liftoff) on the camera lens. In regard to the computational time, the system was also able to process and execute motion detection features on every one of the 30 frames per second generated by the image acquisition system.

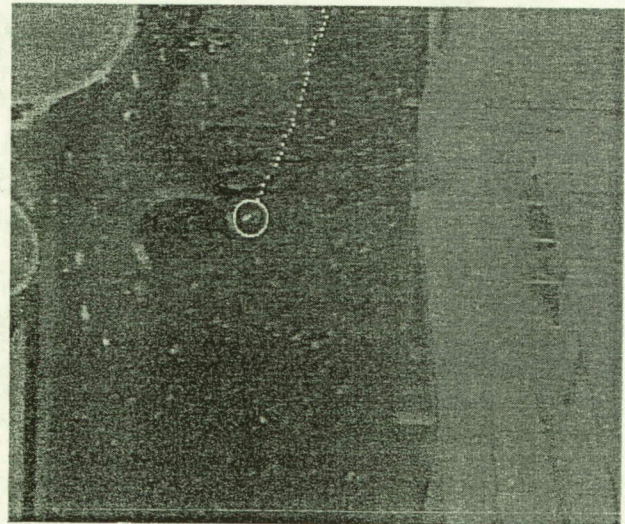


Figure 1. Moving debris (apparently a screw) detected and its trajectory tracked in real time.

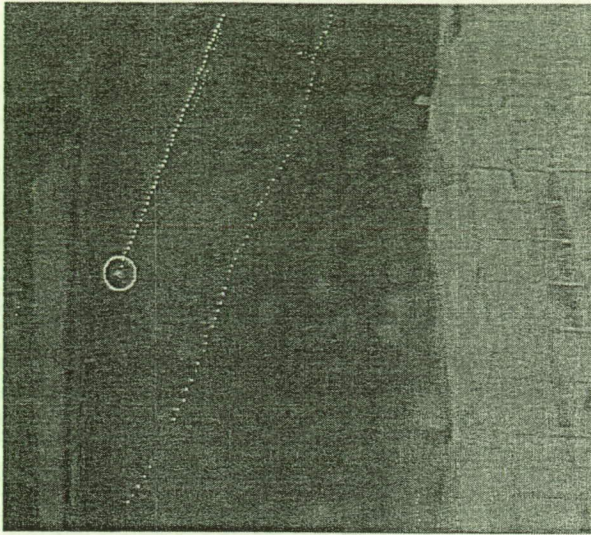


Figure 2. Second moving debris (unknown) detected and its trajectory tracked in real time.

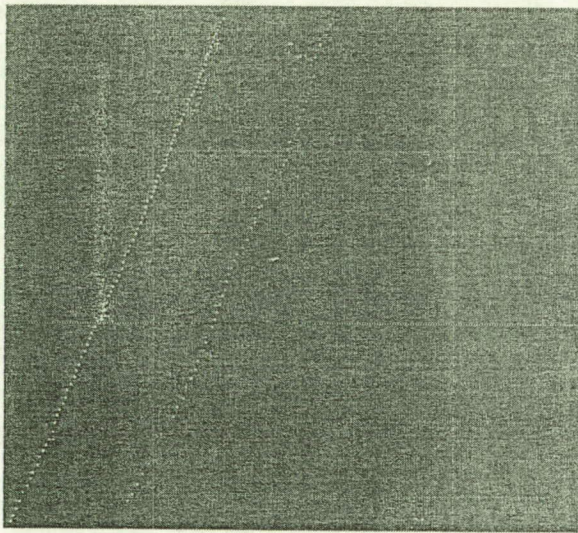


Figure 3. Trajectory of both moving debris drawn in real time and saved for further analysis.

This real-time object moving detection system is currently in its preliminary stage. The system's concept and its algorithm have proven to be robust. Further work on implementation and validation is still needed. The current system works using black and white image format. Image acquired in color would lead to an even more robust system that is not necessarily slower because a multiprocessing CPU approach is quite feasible. Individual CPUs would independently process each primary color.

The potential applications for object real-time moving detection and object's tracking in complex image background include analysis of aerial images, dynamic surveillance, robot vision, detection of moving target, analysis of traffic flow, and autonomous vehicles.

Real-Time Visual Anomaly Detection on Slidewires.

Visual analysis prototype system uses slidewire images acquired by a NASA-built image acquisition system known as Cable and Line Inspection System (CLIM). The system performs image segmentation using the same segmentation FR-based techniques utilized in the above FOD detection prototype application to separate the slidewire image from the image background, preprocesses the image, and performs the final segmentation to retrieve regions/blobs with potential anomalies or defects. Regions/blobs with anomalies or defects are classified and finally retrieved using a learning model built via available PNN and GA techniques. In experimental tests the visual system detected (in real time) all the anomalies classified under the same anomaly class (loose slidewire strand) during the training session.

NASA built 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 4 shows astronauts practicing emergency egress at the Shuttle launch pad; Figure 5 shows CLIM being tested at the Shuttle pad.

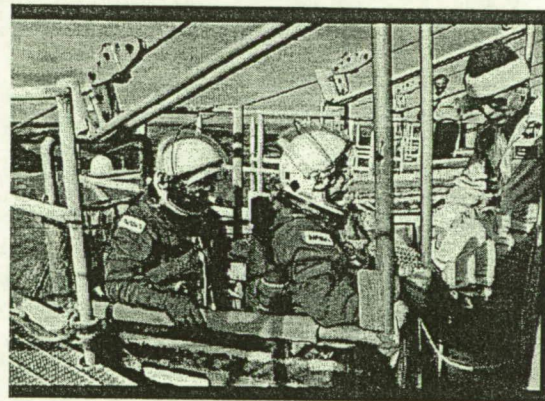


Figure 4. Astronauts at the emergency egress system at the Space Shuttle launch pad.

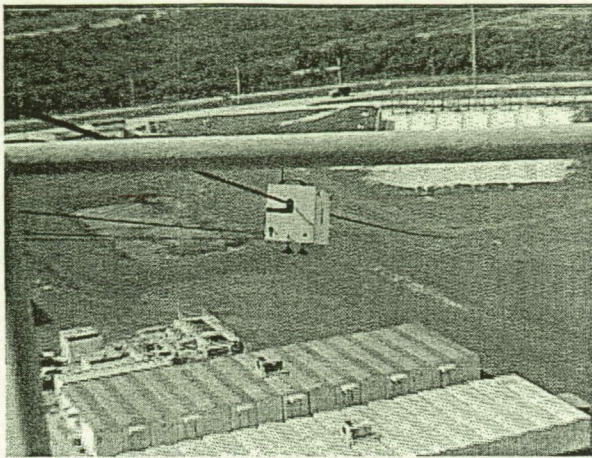


Figure 5. CLIM sliding a slidewire and acquiring images via three cameras positioned in different angles.

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 6 is a PC's screen snapshot showing a slidewire anomaly detected by the system.

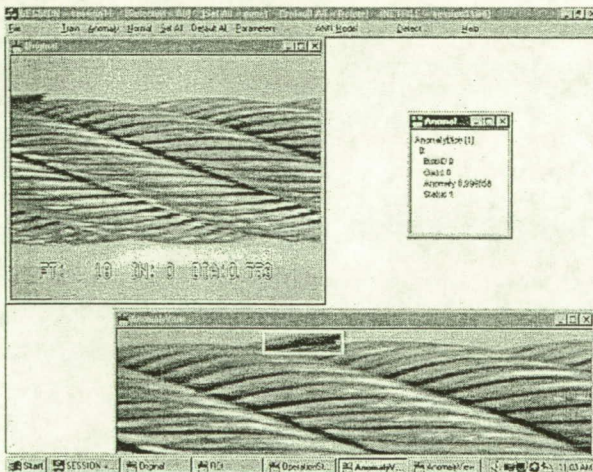


Figure 6. System software screen displaying a detected anomaly (a loose strand).

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. A commercial application using the imaging techniques and entire learning approach is currently being

explored to build a visual ovarian tumor detection system via ultrasound images.

X-ray Image Enhancement.

The above FR-based technologies have also proved its prospective in enhancing x-ray images used to screen hard-covered items leading to a better visualization. Since the appearance of an x-ray film image is a plane in two dimensions of a structure built in three, the image is seen to contain a number of regions within the object superimposed on the background level. Therefore to extract the contours of these different regions, it is necessary to have prior enhancement of the contrast levels among them. The FR-based enhancement technique developed at NASA successfully deals with these problems.

Preliminary tests to enhance x-ray images acquired at Johnson Space Center to screen pyrotechnic devices were conducted with very promising results. Figure 7a shows an x-ray image of a pyrotechnic valve. Figure 7b shows the FR-based enhancement of the original x-ray image (figure 7a) leading to an unquestionable better visualization of the pyrotechnic devices. Figure 7c shows the FR-based image segmentation performed to the original x-ray image (figure 7a) that leads a perfect binary separation of the devices (white) from the rest of the image or background (black).

Both figures 7b and 7c images were generated using the same FR-based techniques.



Figure 7a. Original x-ray image of two pyrotechnic valves.

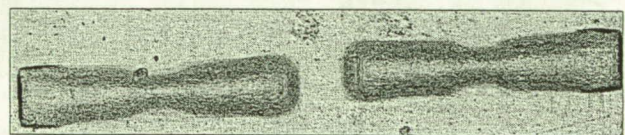


Figure 7b. X-ray image enhancement via edge extraction.

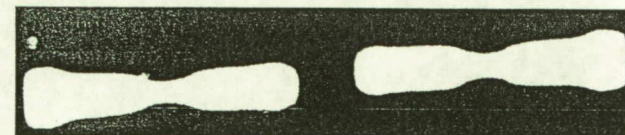


Figure 7c. X-ray image segmentation via binarization

The screening enhancement might be easily applied to x-ray images currently acquired to screen luggage at airports, containers in terminal ports, etc.

Image Analysis on Columbia Accident Investigation.

The set of FR-based imaging technologies was utilized in support of the Space Shuttle Columbia accident investigation on the detection and trajectory-speed estimation of the foam debris that hit the Orbiter left wing. Two image acquisition sources, running at different frame rates and acquiring Shuttle's images from different angle views and positions, were used to automatically detect the foam debris and estimate its 3D trajectory as well as its respective 3D speed.

The detection of the foam debris and determination of its respective borders/perimeters at each one of the 2D image frames acquired by the two image acquisition sources were performed by the FR-based image techniques. The image techniques used here were able to autonomously (not interactively) detect image blobs from two different image acquisition sources, one a film camera with a relative good resolution and definition and the other a video camera with a poorer resolution and definition. These techniques also have proven to be effective in detecting moving objects or debris during the Shuttle liftoff. In contrast with other moving object detection approaches, these techniques do not need consecutive frames to detect moving objects. These techniques actually detect the image blob formed by the debris. The geometrical properties (center of mass, area, perimeter, etc.) of the image blob are also those of the debris. The center of mass is the one used to physically locate the debris in 2D images.

The FR-based segmentation technique also used in all above applications detected the foam debris in all image frames generated by both image acquisition sources (film and video). Figure 8 shows two consecutive images acquired by the same film-based image acquisition source within a 16-millisecond time difference. In both image frames the contours of the detected foam debris were automatically drawn. Figure 9 shows the third image acquired by the video-based image acquisition source 4 ms after the first image was acquired by the film-based image acquisition source (see figure 8). The foam debris was detected by the same FR-based segmentation technique and marked with a yellow dot.

Additionally, this work presents a simple-to-implement approach to automatically determine the position, trajectory, and speed of moving debris when images of the objects are acquired by 2 image acquisition sources running at different frame rates.

Conclusion.

One of the main challenges in next-generation image processing will be the capability of building autonomous, noniterative, flexible, adaptable systems that are capable of performing complex image analysis. After three decades of research, there is still not a general computer vision approach capable of providing the technology to develop a general-purpose vision system able to deal with different tasks and images (like the human vision apparatus).

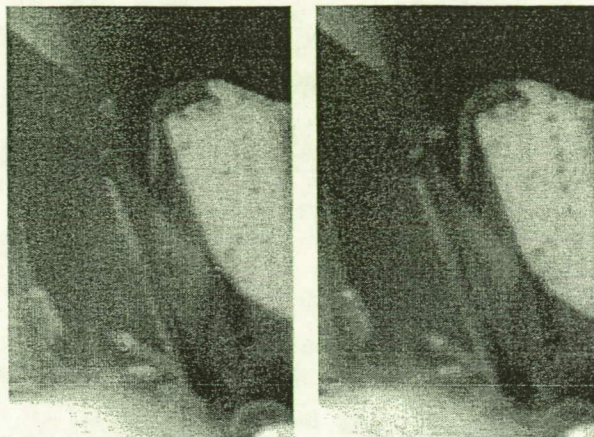


Figure 8. Images acquired from the same image acquisition source within 16-ms difference.

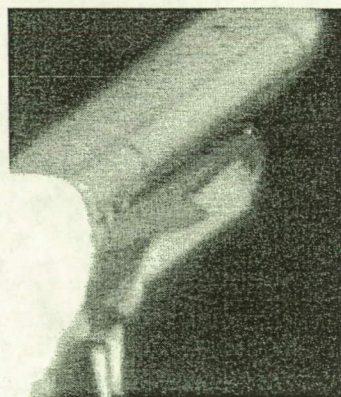


Figure 9. Image acquired from a second image acquisition source 4 ms after the first image (figure 8) was acquired.

A set of imaging techniques based on FR approach and intended for use in general-purpose computer vision systems was built for NASA at KSC to perform a variety of real-time image analysis and information extraction from varying scenes or images. NASA is currently offering these techniques for commercialization. Companies from different fields (including security, medical, text digitalization, and aerospace) are currently in the process of licensing these technologies from NASA.

References.

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