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Title: VIDEO IMAGING FOR NUCLEAR SAFEGUARDS

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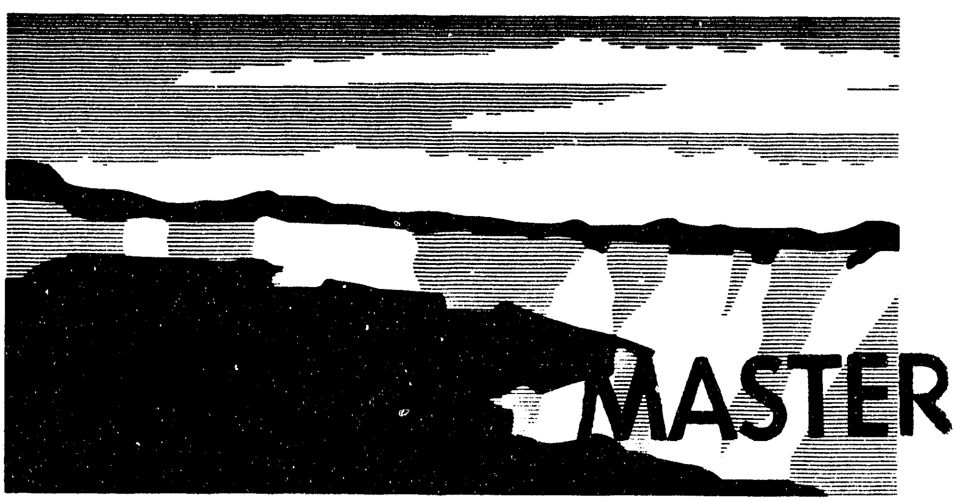

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Video Imaging for Nuclear Safeguards

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I. INTRODUCTION

The field of Nuclear Safeguards has received increasing amounts of public attention since the events of the Iraq-UN conflict over Kuwait, the dismantlement of the former Soviet Union, and more recently, the North Korean resistance to nuclear facility inspections by the International Atomic Energy Agency (IAEA). The role of nuclear safeguards in these and other events relating to the world's nuclear material inventory is to assure safekeeping of these materials and to verify the inventory and usage of these materials as reported by states that have signed the Nuclear Non-proliferation Treaty. *Nuclear Safeguards* are measures prescribed by domestic and international regulatory bodies and implemented by the nuclear facility or the regulatory body. These measures include destructive and nondestructive analysis of product materials and process by-products for materials control and accountancy purposes, physical protection for domestic safeguards, and containment and surveillance for international safeguards.

An example of materials analysis may be the destructive analysis of a sample to verify reported enrichment levels, or the nondestructive gamma-ray measurement of materials in storage for quantitative verification. Materials control and accountancy entails tracking of materials through processing, fuel cycles, and reprocessing by implementing procedures and maintaining databases through the material's life cycle. These procedures may include the establishment of "boundaries" within a facility that serve as accountancy points; inventory balances are maintained in the databases and can be analyzed at discrete intervals for inventory differences that may indicate theft or diversion of nuclear materials.

Physical protection measures are used in domestic safeguards and include deterrents that protect materials from theft or tampering. They may include guards, video, fences, and concrete barriers for facility protection, and paper, metal, or fiber optic seals for item protection. Containment and surveillance is used widely in international safeguards and includes seals for item monitoring, radiation detection devices, live video monitoring of facility areas, and recording of facility activities for later review. Recently, this has been done by intelligent systems capable of unattended monitoring and scene analysis, with triggered video recording that provides personnel with specific information about safeguards-related events.

In this presentation we will introduce digital video image processing and analysis systems that have been developed at Los Alamos National Laboratory for application to the nuclear safeguards problem. Of specific interest to this audience is the detector-activated predictive wavelet transform image coding used to reduce drastically the data storage requirements for these unattended, remote safeguards systems.

II. THREE VIDEO-BASED SURVEILLANCE SYSTEMS DESIGNED FOR NUCLEAR SAFEGUARDS APPLICATIONS

Until recently the use of video in domestic safeguards has been limited to live video displays located in central monitoring rooms. Typically these displays are in banks of nine or more monitors and are mainly used to view areas where other sensors have triggered an alarm. In international safeguards, still frames and video have been widely used for over ten years to record time lapse information about facility operations.

Early international still-frame systems simply recorded a still frame on film at predetermined intervals with the aid of an external, mechanical trigger. The film was periodically collected, developed, and reviewed by inspectors from the regulatory body. Current systems take advantage of personal computer and analog/digital tape technologies to drive the cameras and store the time-lapse imagery. Single images are collected by the computer system at programmed intervals, or when triggered by an external sensor, and recorded to tape that is then periodically (up to 3 months) collected and reviewed by the inspector.

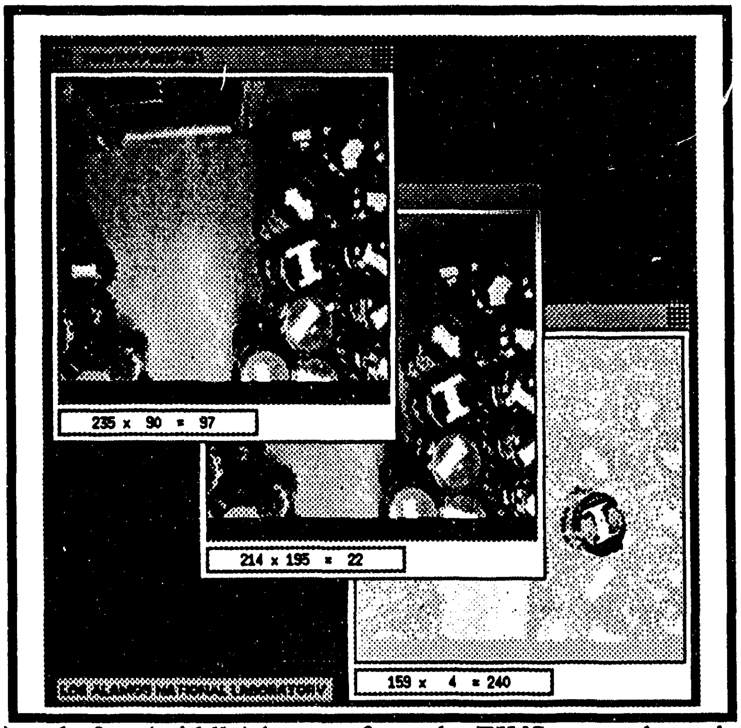
The Los Alamos Experimental Inventory Verification System (EIVSystem) is a prototype developed to test the use of intelligent, automated surveillance in domestic safeguards. This system is installed at two DOE facilities and is currently undergoing final software modifications. It is scheduled to be fielded in the summer of 1994 as the MONITOR Surveillance System. Two other Los Alamos video systems, the Video Time Radiation Analysis Program (VTRAP) and a design-stage system currently called just "Alpha," are designed to be next-generation video systems for domestic and international safeguards.

A. The Experimental Inventory Verification System

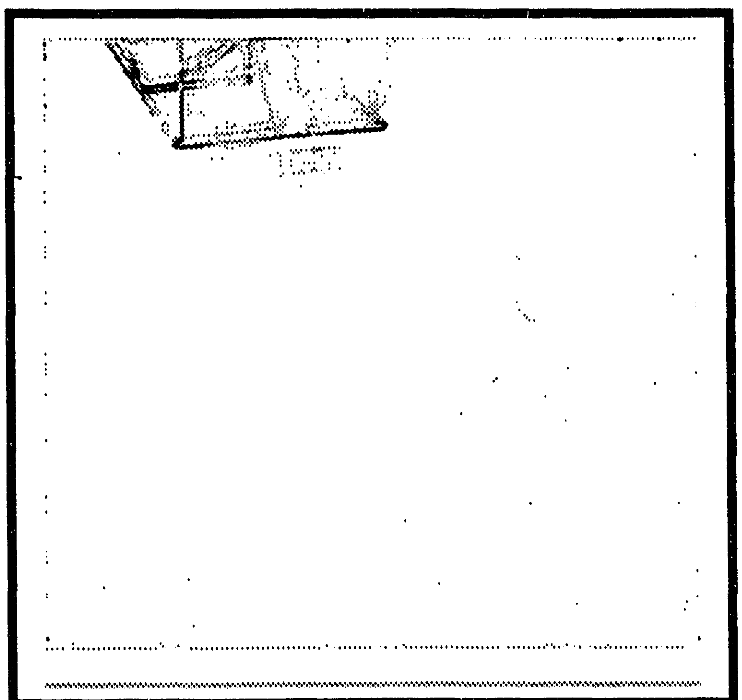
The EIVSystem is a video-based surveillance application designed to help reduce the frequency of physical inventories in domestic nuclear materials vaults and long-term stores[5]. This surveillance system is CPU-based and configured with one or more Charge Coupled Device (CCD) cameras, a hard disk data store, and a tape archival system. The current implementation uses a Sun Microsystems SPARC 10 architecture.

The EIVSystem is part of an overall defense-in-depth protection strategy that relies on multiple layers of security to provide complementary nuclear safeguards measures. This surveillance system is viewed as being effective against the "insider threat" since it is not dependent on traditional monitoring devices that rely on receiving a positive signal to trigger an alarm. Such mechanisms, e.g., motion detectors, are perceived to be more vulnerable to insiders with a knowledge of the security apparatus. By contrast, difference coding of video images provides a constant verification of either the presence or absence of changes in the system's state. Under new Department of Energy (DOE) guidance on the use of "Alternative Security Measures," the EIVSystem qualifies to reduce the required frequency of physical inventories and is instrumental to the DOE policy of keeping the radiation exposure of personnel "As Low As Reasonably Achievable."

Data from the EIVSystem cameras installed in the vault or storage area is transmitted via fiber optic cable to a safeguards office complex. There it is processed by the host computer, analyzed



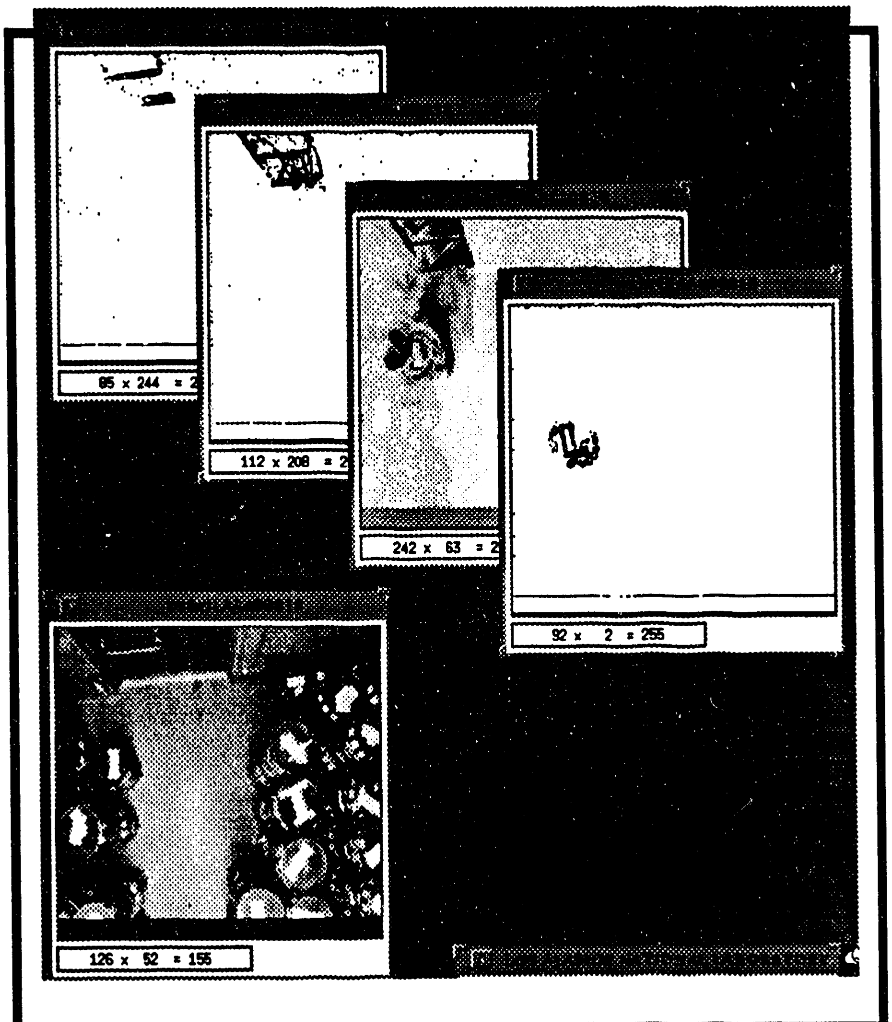
Before (top) and after (middle) images from the EIVSystem show the movement of a drum (bottom) that may indicate tampering or a theft of material.
Figure 1a.



Difference data detecting the vault doors being opened for an authorized alarm check.
Figure 1b.

for events, and if an event is detected, it is video recorded using wavelet transform image coding. This data are reviewed weekly by safeguards personnel to determine if any detected events have safeguards significance. Figures 1a, 1b, and 1c show events detected by the EIVSystem.

In Figure 1a, scenes from before and after a legitimate maintenance access to the vault are analyzed. (A "maintenance access" is to service security or other equipment; no access to storage items is authorized.) The top image represents the vault before access; the middle image represents the vault after the access; the "difference" data shows that an unauthorized access or movement was made to one of the drums in storage. Figure 1b shows a detected event without safeguards significance: the doors of the vault being opened by security personnel for an alarm check. Figure 1c shows data detecting the removal of a drum from the vault. In all cases, detected events trigger the storage of wavelet coded video and may send an alarm to a central alarm station.



Difference data (top, left to right)
detecting access to the vault and subsequent removal of a drum.
Figure 1c.

B. Video Time Radiation Analysis Program

As more facilities throughout the world are coming on-line, inspectors are necessary at these facilities to assure that proper safeguards are in effect. Because of this increased activity and budgetary realities, it is desirable to reduce inspector time at each facility without losing safeguards effectiveness. The Video Time Radiation Analysis Program [6] is designed to compile data from numerous sensors, including gamma or neutron detectors, motion sensors, video systems, etc., and use neural network and pattern recognition methods to:

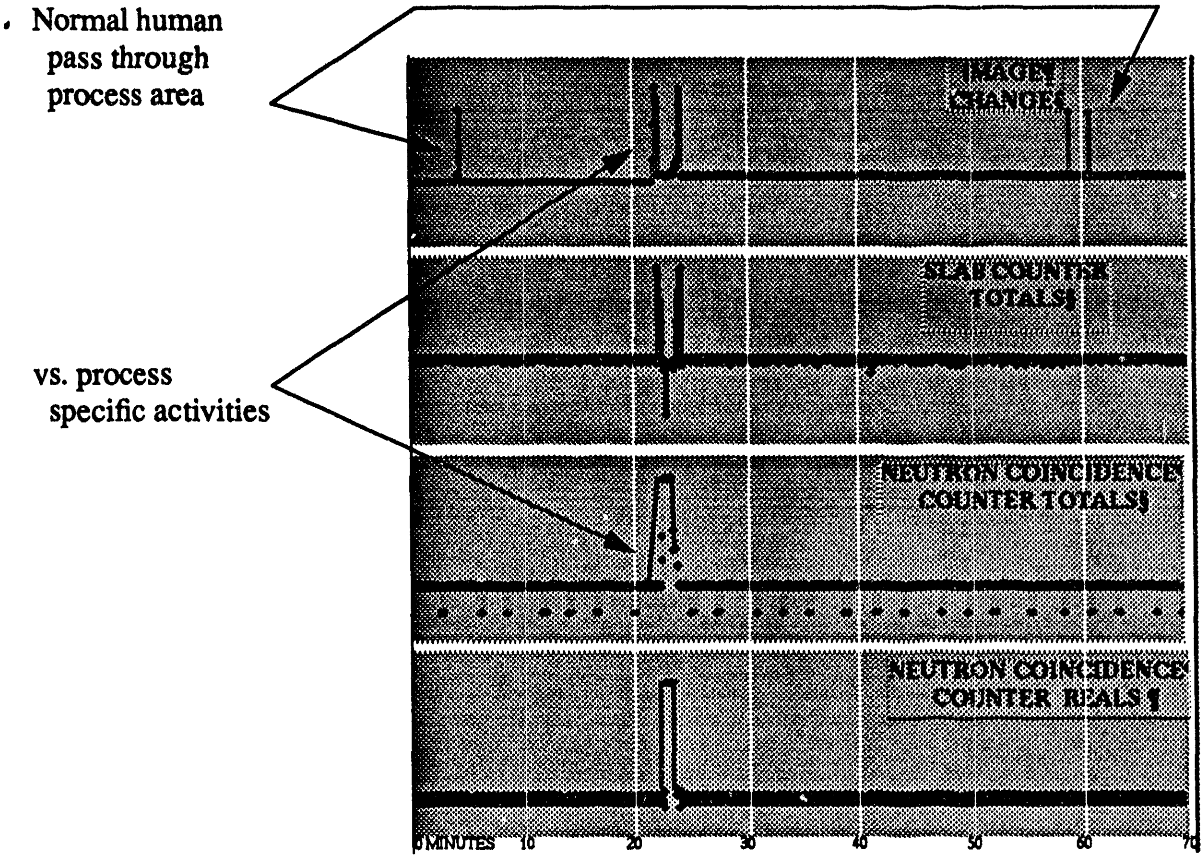
- Correlating large quantities of diverse information;
- Identifying abnormal activity, such as diversion of material or faulty data from intermittent sensors;
- Develop inferences and conclusions;
- Increase inspector efficiency by providing routine analysis of all data, identifying specific trends and flagging data to be checked by an inspector, and relieving the tedium of reviewing masses of information; and
- Automatically verifying plant operation.

A simple example is illustrated in Figure 2. Two radiation detectors and a video camera are installed at a facility to monitor process events. A normal event consists of a technician removing some nuclear materials from a vault, walking past a radiation detector, and depositing the material in a neutron counter. The technician then removes the material from the counter, walks back past the detector, and deposits the material back into the vault. The spikes in the center of Figure 2 represent the data gathered by each sensor.

First the figure shows a video spike where the technician enters the area; next a neutron detector spike appears as the technician walks past; then a neutron counter spike appears when the material is deposited into the neutron counter; and finally neutron detector and video spikes show up as the technician returns the material to the vault. The data are correlated, and a visual picture of a normal process event is quickly displayed to the inspector, saving the time it would take to review each instrument's data separately and draw a conclusion.

Another normal event is a technician merely passing through the area without accessing any nuclear materials. This event is shown by the right-most and left-most spikes on the "Image Change" strip chart. By characterizing these normal events, we can detect *anomalous events* efficiently and accurately, saving an inspector time and increasing safeguards effectiveness.

While continuous, unattended radiation and surveillance monitoring systems can significantly reduce inspector time in facilities, they do produce large amounts of data that must be stored for the duration of the inspection period. Thus, appropriate compression methods applied to the data become critical to the success of such systems.



Data collected from multiple safeguards instruments is correlated and analyzed to detect anomalous activities at a nuclear facility.
Figure 2.

C. Alpha: A LANL/EURATOM Remote Video Surveillance System Design

EURATOM is a nuclear regulatory body for the Commission of European Communities and, like the IAEA, is responsible for safeguarding nuclear materials in many European countries. The Alpha design currently underway at Los Alamos will provide EURATOM with an unattended, remote surveillance system that uses a new wavelet-transform image coding method to store video data representing facility activities. This video data will be periodically collected by inspectors and reviewed to verify operations reports submitted to EURATOM by the facility operator.

This system will be similar in architecture to the EIVSystem, except that data collection and review functions will be performed at different locations. The data collection component of Alpha will consist of a host computer configured with one or more CCD cameras and digital storage devices capable of storing 3 to 6 months of surveillance data. In this application the data compression method is critical to the success of the system because it must run unattended without the possibility of data stores becoming full before the end of the surveillance period.

In contrast to existing surveillance systems that rely on external motion sensors, Alpha will use the wavelet transformation of frame differences for event detection, reducing reliance on external motion detectors. This strategy will enable event-related data collection instead of 24-hour time-lapse data collection. Alpha will also allow the inspector to configure specific regions of interest so that facility activities of no interest will typically not trigger event recording. The overall goal of this design is to record only data relevant to safeguards, thus reducing the amount of data an inspector needs to review for a given surveillance period.

At the end of a surveillance period, the digital video data are collected by the inspector and transferred to a local site for review, where the "data viewer" will perform the video reconstruction using wavlet-transform image decoding.

III. VIDEO COMPRESSION

Data storage capability is of primary importance to the viability of the three systems described above. This is especially true for international safeguards, where unattended surveillance periods are currently up to 3 months and could increase with increasing inspection activities and decreasing budgets. To achieve the required compression ratios and maintain minimal loss of quality in the reconstructed images, we determined that commercially available solutions like the ISO "JPEG" image compression standard were not adequate. Instead, we adopted a wavelet-transform compression algorithm based on predictive image coding strategies, currently being developed at Los Alamos.

A prediction of each frame is made based on the previous frame, and the error residual (the difference between the actual and predicted frames) is coded for storage or transmission or both. The change detection algorithm plays an important role in the compression process in that it is used to adjust the quality level in the frame-difference coder based on the activity in the scene. By using relatively low quality coding on frames with little activity, very large compression ratios can be realized.

A. Discrete Wavelet-Transform Image Coding

Compression of image frames is based on discrete wavelet transform (DWT) sub-band coding and adaptive uniform scalar quantization. The sub-band coder is a two-channel perfect-reconstruction multi-rate filter bank (PR MFB) with linear-phase FIR filters corresponding to a family of regular, biorthogonal wavelets; this same PR MFB is used in the FBI's wavelet/scalar quantization (WSQ) standard for coding digital fingerprint images [1, 2]. The filters are applied to row and column vectors of an image using symmetric extrapolation at the image boundaries; this "symmetric wavelet transform" technique is detailed in [3]. The resulting two-dimensional transform is then cascaded down five levels to produce the 16-band octave-scaled decomposition shown in Figure 3. Note that this particular decomposition has fewer sub-band splittings than the decomposition employed in [1], which was tailored to preserve very fine details in fingerprint images at the expense of slightly increased ringing distortion near edges.

Once the DWT decomposition of an image has been formed, a bank of 16 uniform scalar quantizers is designed for quantizing the wavelet coefficients in the 16 sub-bands, based on the following optimal bit-allocation problem: minimize the scalar quantization distortion model

$$D(\mathbf{r}) = \sum_{k=1}^{16} \frac{1}{m_k} \sigma_k^2 2^{-2r_k} ,$$

subject to the user-imposed overall bit rate constraint

$$\sum_{k=1}^{16} \frac{r_k}{m_k} = R,$$

Here, m_k is the down-sampling ratio for the k^{th} sub-band; e.g., the bands between $\frac{\pi}{2}$ and π in Figure 3 have been down-sampled 2:1 in both the horizontal and vertical directions, so $m_k = 4$ for those bands. The other bands have down-sample factors that are higher powers of 4. The Lagrange multiplier solution to this bit allocation problem is

$$r_k = R + \frac{1}{2}\log_2\left[\frac{\sigma_k^2}{\prod_j \left(\sigma_j^2\right)^{1/m_j}}\right],$$

which involves a "scaled" geometric mean of the sub-band variances. The derivation of this result is based on the assumption that

$$\sum_k \frac{1}{m_k} = 1,$$

a relation that holds for any critically sampled sub-band decomposition. An iterative procedure is used to eliminate sub-bands with negative "optimal" bit rates and ensure non-negativity of the r_k's.

The integer quantizer indices generated by the scalar quantizers are then compressed by zero-run-length and Huffman coding. Low bit-rates for the high-frequency sub-bands produce long runs of zeros in those portions of the sub-bands corresponding to smooth regions of the image; this is the principal source of additional lossless coding gain over and above the lossy gain produced by wavelet coefficient quantization. Note that this technique makes use of the good space/frequency localization properties of sub-band image coding with short FIR filters.

B. Predictive Coding of Image Sequences

Now consider coding a sequence or "run" $x_0, x_1, x_2, \ldots$ of consecutive images taken by a still surveillance camera monitoring a scene of interest. The goal is to provide an uninterrupted record of surveillance images at very low storage costs during periods when the scene is inactive, yet obtain high-quality imagery during active periods. The initial frame rate is therefore assumed to be "low," e.g., one frame every few seconds. The initial frame in a run, x_0, is compressed using nonpredictive coding. Because no motion is presumed to occur in the scene in the inactive state, we use a simple first-order predictor and code the difference frames for subsequent time-steps, $x_i - \hat{x}_{i-1}$, where $\hat{x}_{i-1}$ is the reconstructed, quantized approximation of x_{i-1}. The DWT is a linear transformation, so the transform d_i of the i^{th} difference image can be computed by taking the difference of the DWTs, a_i and $\hat{a}_{i-1}$, of x_i and $\hat{x}_{i-1}$:

$$d_i = DWT(x_i - \hat{x}_{i-1}) = a_i - \hat{a}_{i-1}$$

This eliminates the need to perform an inverse DWT inside the prediction feedback loop, improving on the predictive scheme described in [4]. Note that a_i consists of 16 separate spatial frequency sub-bands, as shown in Figure 3, so "d_i" denotes the difference signals for the 16 DWT sub-bands. The transformed difference d_i is quantized by the bank of uniform scalar quantizers described above and Huffman coded for transmission; the block diagrams for this predictive encoder/decoder system are shown in Figures 4 and 5.

While the scene is inactive, the frame-to-frame differences are extremely small and can be coded at a very low bit rate with little perceptible distortion, allowing a continuous record to be archived at a low storage cost. Of course, as soon as an event occurs and the state becomes active, a much higher bit rate is needed to record the event accurately. A major advantage of adaptive scalar quantization is that the user-imposed overall bit rate R_i can be changed on the fly. In most image-sequence coding scenarios, it is very difficult to maintain constant perceptual image quality by automatically measuring scene content and adaptively modifying the quantizer bit rates. In the specialized remote surveillance scenario under consideration, however, image coding conditions divide naturally into active/inactive states, and there is a straightforward criterion for deciding when and by how much quantizer bit rates should be changed.

In Figure 4 we have indicated how the transformed difference image, coupled with input from other sensors (e.g., motion or radiation sensors) can be fed to an event detector that automatically triggers a higher bit rate (and possibly an increased frame rate) in response to an event detection. Bit rates for the inactive state can be preset to minimize the amount of data required to verify that the scene remained unchanged when sensors detected no activity, and bit/frame rates for active states can be set high enough to provide necessary resolution for monitoring activities. This accomplishes our dual goals of providing uninterrupted coverage of the scene at very low storage cost during inactive states while still producing high-resolution coverage of active states.

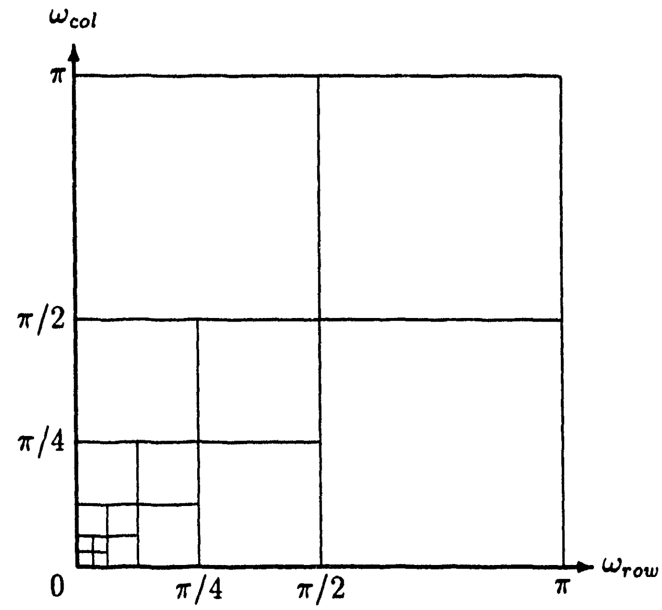


Figure 3: Approximate frequency passbands for five-octave DWT decomposition.

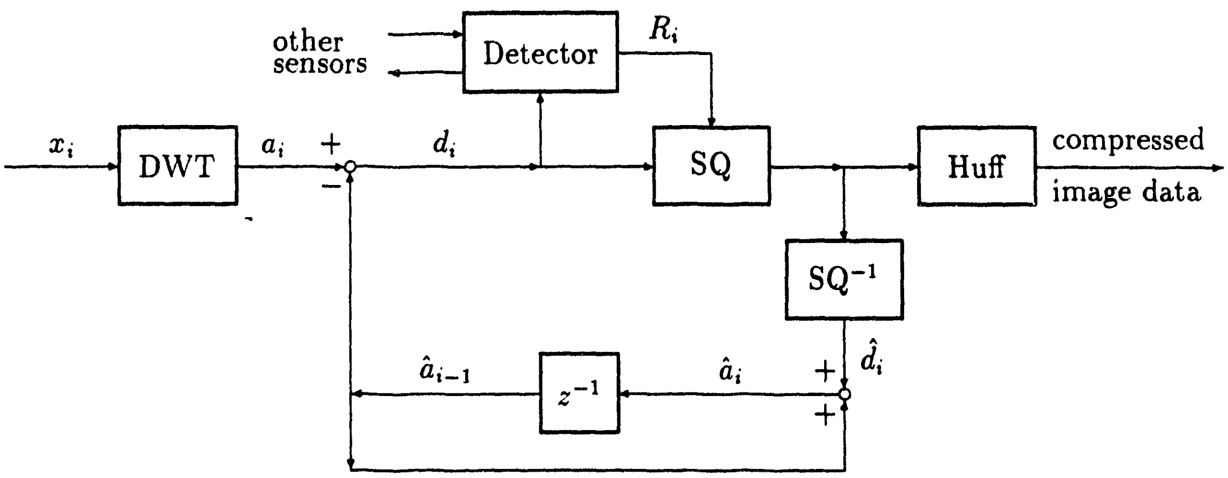


Figure 4: Detector-activated predictive wavelet transform image coder.

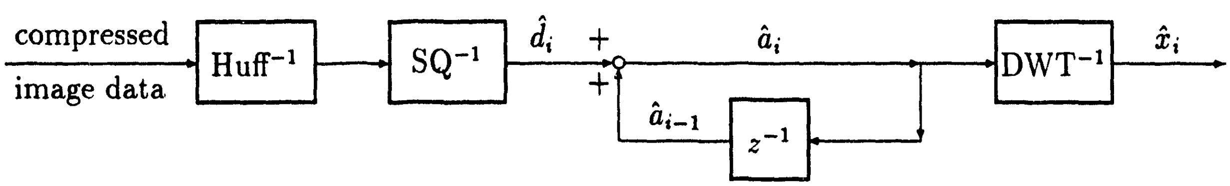


Figure 5: Predictive wavelet transform image decoder.

IV. FUTURE EFFORTS

Future efforts will involve research in the area of change detection. We believe that wavelet transformation of frame differences is a good preprocessing method for event detection. Currently, change detection is performed by a threshold test on differences of successive frames. Such a scheme can be confused by lighting changes (e.g., a light bulb burning out), resulting in a false alarm. Because the wavelet transform separates image information into components from different length scales, false alarms due to low-frequency changes in scene content, such as changes in lighting, or high-frequency changes, such as insects or rodents in the scene, could be eliminated by performing threshold detection in certain sub-bands of the wavelet decomposition. If the image differences are being processed in the wavelet domain for compression purposes, it is natural to perform event detection with this readily available image data. We plan to investigate the feasibility of using wavelet-transformed image data for event detection in conjunction with other non-image based sensors, as indicated in Figure 4.

V. CONCLUSION

Video systems have long played an important role in international safeguards and promise to be important in future domestic safeguards strategies. Advances in computer and multi-media technologies allow new video systems to perform increasingly sophisticated functions, which include video analysis, multi-sensor integration, pattern recognition, anomaly detection, and long-range transmission of raw or processed video surveillance data. These capabilities will help enable regulatory bodies world-wide to assure safekeeping of nuclear material inventories by reducing the currently extensive requirementson data review by humans and by extending the length of surveillance periods through the use of video processing and analysis, integrated data correlation, and the use of state-of-the-art data compression techniques.

REFERENCES

[1] T. Hopper, FBI, C. Brislawn, and J. Bradley, Los Alamos National Laboratory, CIC-3, *WSQ Gray-Scale Fingerprint Image Compression Specification,* IAFIS-IC-0110V2, Criminal Justice Information Services Division, Federal Bureau of Investigation, February 1993.

[2] J. Bradley, C. Brislawn, Los Alamos National Laboratory, CIC-3, and T. Hopper, FBI *The FBI Wavelet/Scalar Quantization Standard for Gray-Scale Fingerprint Image Compression,* in Proceedings of the Conference for Visual Information Processing II, vol. 1961 of the Proceedings of the SPIE, (Orlando, FL), pp. 293-304, Society of Photo-Optical Instrument Engineers, April 1993.

[3] C. Brislawn, Los Alamos National Laboratory, CIC-3, *Classification of Nonexpansive Symmetric Wavelet Transforms,* Technical Report LA-UR-93-2236, Los Alamos National Laboratory, May 1993.

[4] J. Bradley and C. Brislawn, Los Alamos National Laboratory, CIC-3, *Applications of Wavelet-Based Compression to Multidimensional Earth Science Data,* in Proceedings of the Space Earth Science Data Compression Workshop, no.3191 in NASA Conference Publication, (Snowbird, UT), pp. 13-24, National Aeronautics and Space Administration, April 1993.

[5] C. Rodriguez, Los Alamos National Laboratory, NIS-7, *Video Image Processing for Nuclear Safeguards: The Experimental Inventory Verification System,* Technical Report N4/93-343

[6] J. Howell, C. Rodriguez, and R.Whiteson, NIS-7, J. W. Eccelston, J. K. Halbig, H. L. Menlove, S. F. Klosterbuer, NIS-5, M. F. Mullen, NIS/SG, Los Alamos National Laboratory, *Safeguards Applications of Pattern Recognition and Neural Networks,* in Proceedings of the IAEA Symposium on International Safeguards, (Vienna, Austria), March 1994.

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