Computerized Realtime X-Ray Inspection of Consumer Waste Product for Hazardous Materials

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ABSTRACT

This presentation describes the design and manufacture of a computer controlled x-ray scanning system for the fully automated inspection of waste for hazardous materials. Of particular importance was the necessity to accurately detect various sizes of propane tanks and large heavy metal objects. In addition, rejects had to be accurately identified and each image saved for archival requirements. The equipment utilized, material handling, software development and implementation is detailed herein. The problems of establishing a stable image in a harsh environment required ruggedizing all of the components as well as positive pressure air delivery and air conditioning of the computer and related electronic enclosures. The use of commercially available equipment and latest detector technology were utilized as much as possible to reduce costs and to provide a reliable low maintenance system that also included the ability to conduct diagnostics and software upgrades remotely via computer.

INTRODUCTION

The implementation of conventional x-ray imaging, ie., image intensifiers, standard linear diode arrays (LDA’s) in the inspection of waste could not be employed due to the various size conveyor tunnels, height of waste product and speed. This type inspection had to be conducted under very adverse conditions and in some instances continuously 24 hours a day. It was not possible to stop the stream of waste from the tipping floor nor to control its distribution within the conveyor. Until recently realtime x-ray has also been employed in numerous industrial applications but primarily as a manual operation where a technician makes the final acceptance or rejection decision. Computer processing of digitized radiographs has also emerged as has some automated systems where pattern recognition has been the main criteria for accept/reject analysis.

The instant requirement was to develop a fully automatic inspection system capable of inspecting waste automatically while providing a visual and audible signal to the crane operator of suspect contaminants. The operator would stop the line briefly while picking the suspect object from the conveyor. Conveyor size, speed, and depth of waste had to be taken into consideration when coming up with a design that would satisfy most if not all similar inspection applications. Until now this inspection operation was strictly manual, left to the tipping floor staff or crane operator. Undetected propane tanks that reach the shredder could result in a
possible serious explosion with possible personal injury and costly system downtime. Undetected heavy metal objects damage the shredder hammers, causing costly system downtime.

Raw and processed propane tank image

**Hardware/Design**

An important design criteria was to manufacture a system utilizing as much “off-shelf” or existing technology as possible. This was critical from three primary standpoints, one was time. There was a need to deliver a system quickly which would not permit for the development of any specialized x-ray or electronic systems. Second, ease of field service which made a module type of design attractive as well as assure availability of spare components. The final point was reliability, in order for the system to perform virtually non-stop, the components and design had to be proven to as much extent as possible.

The x-ray generator selected was a constant potential 160kVp 3mA fine focus system. The x-ray tube was a major consideration in that it would be subject to continual use in a harsh environment. As the waste would be in close proximity to the x-ray tube the focal spot selected provided the least amount of geometric magnification or distortion. A small focal spot size was also utilized to eliminate image unsharpness.

The original linear diode array selected consisted of a single line of photosensitive diodes with an x-ray sensitive scintillator applied to the surface of the diode which converts the x-ray energy into visible light producing a single line of image data the length of the array. As the conveyor moves each line is displayed on the image display monitor providing a continuous realtime x-ray image of the waste product as it moves between the x-ray generator and the LDA. Subsequent field testing resulted in the selection of a dual energy detector which gave the added benefit of being able to detect and separate organic and inorganic materials by color. This was significant developing software that would lessen the chance of false rejects and in aiding the crane operator in his visual identification of objects that were detected.

With most LDA based x-ray systems there is a calibration required periodically, the only requirement was to have a brief space in the waste where the x-ray beam was clear of all refuse for a few seconds. This was easily accomplished by introducing a slight delay in feeding the waste from the tipping floor which provided an almost seamless flow of material. Light barriers across the conveyor would detect the necessary space and the calibration is performed automatically by the systems computer.
Radiation safety to personnel was an obvious concern, however the actual x-ray beam is a narrow 1mm fan shaped pencil beam, highly collimated and perfectly aligned between the x-ray generator and LDA. This greatly limits the amount of stray or scattered radiation and operating personnel could work if required in very close proximity to the system. All construction is in strict accordance with the Bureau of Radiological Health CFR Part 21 and all State agency requirements. Shielding to Bureau of Radiological (BRH) CFR Part 21 and State requirements. Training in radiation safety is also provided to the crane operators and maintenance personnel.

Environmental Considerations

The system was designed to operate in the environmental conditions typically found in the Tipping Building of a Municipal Solid Waste handling facility. That is, considerations were given to ambient air temperature, humidity and dust loading. There is no temperature control, with conditions being very hot in the summer and, depending on location, quite cold in the winter months. Humidity was a concern with respect to the computer control system. The solution was to provide heat and air conditioning units in the electronics control enclosure and positive air and filters to the x-ray generator enclosure. The LDA is a sealed unit with no openings to the outside environment. In over one year of continuous operation, there have been no electronic failures due to the environment conditions.

The installation of the primary hardware also necessitated changes not found in less harsh installation. The pan type conveyors used are prone to a fair degree of vibration, not to mention the sides of the conveyor being often hit by the claws of the crane during picking operations. It was determined it was best to mount the x-ray generator and LDA slightly off from the conveyor so both modules were on independent frames not subject to vibration or shock. Where a platform is an absolute requirement, shock mounts were provided between the components and framework of the conveyor.
Software and Archival Storage

The proprietary software program was developed by SDS and written in "C" for the Windows™ operating system. Later a new upgrade was provided in Windows™ NT which enabled a faster and more reliable. All operations are menu driven and once the inspection/reject parameters are established there is no operator interface required. Since the x-ray images are in constant movement it was not feasible to save the images to disk. It was also determined that there was no reason to review the images unless an event were to occur where it would be of benefit to go back to view what possibly could have been missed. Here a high resolution tape recording was made which would run for twenty four hours and then automatically tape over the same cassette on a continuous basis.

Computerized inspection image processing hardware consisted of a Pentium PC with floating point co-processor, realtime image processing single PC/AT board running at 40ns per pixel (25 megapixels per second processing speed - 700MIPS) Four channel RS-170 input, multiplexed digitizer 8 bits; upper and low limits software controlled.

The system software is a two level package consisting of the operator interface and the image enhancement algorithms. Top level software consists of the menu-driven operator interface which provide access to the set-up and run-time parameters, size/density configurations for the detection and identification of the propane tanks and heavy metal object. This includes acquiring/storing reference images, setting contrast regions of interest (ROI), setting the difference threshold, setting area threshold, setting run-time enhancement display options.

The second level, or application software consists of the x-ray image enhancement algorithms that have been written around Visual Basic "C" callable functions. Systems software “C” code includes written program for image contrast, averaging and sharpening enhancement, item count verification, image subtraction routines, image gray scale/density identification, contaminant/defect detection by size, automated reject signal (TTL) to activate the crane alarm.

Results

Since this system has been in operation, Operators have detected numerous propane tanks that would have previously been undetected via the normal visual inspection. Propane tanks have been discovered wrapped in blankets and packaged in cardboard boxes. Though the risk of an explosion remains, there has not been a propane tank explosion since the system was installed as compared to anywhere from 2 to 4 explosions per year prior to the installation. The cost of a typical system will vary depending on individual installation requirement, however budgetary costs are in the area of $130,000 per line.

Conclusion

X-ray imaging has proven to be a very useful inspection device in a waste processing facility where the detection of materials as sited could prevent possible injury or costly production down time.