Detection of Construction Flaws in Geomembrane Liners by Image Processing

A. T. Yeung
Texas A & M University, College Station, TX, USA

P. K. Chan
Texas Transportation Institute, College Station, TX, USA

ABSTRACT: The effectiveness of a waste containment system depends primarily on the integrity of the geomembrane liner within the system. However, construction flaws always reduce its effectiveness as physical barriers to contaminant transport. This paper presents a reliable, efficient and cost effective technique to detect these defects in the geomembrane liner by image processing immediately after construction so that any necessary repair can be performed prior to operation of the facility. The video image of the constructed geomembrane liner is recorded by a camcorder. The image is then digitized into pixels and a degree of brightness is assigned to each pixel. The contrast in the degree of brightness allows the identification of a punctured hole down to 1/32″ (0.8 mm) in diameter. The paper will present the results of a laboratory investigation on a GUNDLE HDPE geomembrane using different identification algorithms for punctured holes of different diameters.

1. INTRODUCTION

An engineered double liner system with leachate collection systems above and between liners is required for most waste repository facilities in the United States as promulgated by the U. S. Environmental Protection Agency. These liners contain both synthetic flexible membrane liners (FML) and compacted clay layers. The synthetic flexible membrane liner is supposed to be designed, constructed and operated to prohibit any migration of hazardous constituents through the containment system into the environment (U. S. EPA, 1985). However, construction flaws always reduce its effectiveness as physical barriers to contaminant transport. Cases of groundwater contamination due to these defects have been documented (Bass et al., 1985). Unfortunately, most of these defects are discovered after the containment system has been in operation and excessive quantity of leachate has been collected.

Inspection and repair of in-service geomembrane liner are prohibitive in cost, dangerous to workers, and potentially hazardous to the environment. Careful inspection of the geomembrane liner immediate after construction is very difficult as the constructed geomembrane liner needs to be covered with soil as soon as possible to minimize any possible deterioration by UV light and to facilitate the movement of construction traffic (Koerner, 1990). This paper presents a reliable, efficient and cost effective technique by image processing to detect these defects immediately after construction so that any necessary repair can be performed prior to operation of the facility. The video image of the constructed geomembrane liner is recorded by a camcorder. The image is digitized into pixels and a degree of brightness is assigned to each pixel. The contrast in the degree of brightness allows the identification of a punctured hole down to 1/32″ (0.8 mm) in diameter. The paper will present the results of a laboratory investigation of the technique on a GUNDLE HDPE geomembrane using different identification algorithms.

2. DESCRIPTION OF THE APPROACHES

The videolog of the geomembrane liner can be recorded by a video camera and an illumination system mounted on a specifically designed trailer pulled by a "off-road" vehicle in the field. The recorded videolog can then be fed to an image processor system to be digitized and analyzed. Using advanced computer technology and image processing techniques, the conditions of the liner can be evaluated by processing the videolog of the liner in real time.

Each video frame is first digitized into a 512×480 picture elements known as pixels. A numerical parameter called gray level denoting its shade of gray is then assigned to each pixel. A gray level of 255 usually represents the brightest light level while 0 represents the lowest light level. Flaws on the liner, such as punctured holes and tears, are usually evaluated by the rapid changes in gray level along perimeters of holes and tears.

Two edge detection techniques are applied in the processing of geomembrane liner images in this study. The first technique is called the Sobel edge detector. This detector, unlike other traditional detectors, does not only emphasizes the presence of an edge but also suppresses random noise in the images. The second technique is based on mathematical morphology to increase the size of objects in the image to enhance the object detection rate.

3. SOBEL EDGE DETECTOR

Sobel edge detector is an area operator which is sensitive to the rapid variations of the pixel gray level (Gonzalez and Wintz, 1987). It also suppresses random and isolated noisy spots. This detector accentuates the contrast of an edge segment to its background with a number of weighing factors in a 3×3 neighborhood. Fig. 1 shows the horizontal mask and the vertical mask of the operator which contains two sets of weighing factors for the gray level of neighboring pixels. The horizontal mask is used to extract the horizontal edge segment and the vertical mask for the vertical edge segment within the 3 pixels × 3 pixels area. The magnitude of the vertical gradient of a pixel $\ell_{y_{i,j}}$ is expressed in terms of the sum of the products of the weights in the horizontal mask and the corresponding pixel gray level $f_{i,j}$ using Eq. (1),

$$\ell_{y_{i,j}} = -f_{i-1,\,j-1} - 2f_{i,\,j-1} - f_{i+1,\,j-1} + f_{i-1,j+1} + 2f_{i,\,j+1} + f_{i+1,\,j+1} \quad (1)$$

Similarly, the magnitude of the horizontal gradient is computed using Eq. (2),

$$\ell_{x_{i,j}} = -f_{i-1,\,j-1} - 2f_{i-1,\,j} - f_{i-1,j+1} + f_{i+1,j-1} + 2f_{i+1,\,j} + f_{i+1,\,j+1} \quad (2)$$

The notations used in Eqs. (1) and (2) are depicted in Fig. 2. Finally, the gradient for the pixel $\ell_{i,j}$ is computed as

$$\ell_{i,\,j} = \sqrt{\left(\ell_{x_{i,j}}\right)^2 + \left(\ell_{y_{i,j}}\right)^2} \quad (3)$$

-1	-2	-1
0	0	0
1	2	1

Horizontal Mask

-1	0	1
-2	0	2
-1	0	1

Vertical Mask

Fig. 1. Masks of the Sobel edge detector

$f_{i-1,\,j-1}$	$f_{i,\,j-1}$	$f_{i+1,\,j-1}$
$f_{i-1,\,j}$	$f_{i,j}$	$f_{i+1,j}$
$f_{i-1,\,j+1}$	$f_{i,\,j+1}$	$f_{i+1,\,j+1}$

Fig. 2. Notation for a 3 pixels × 3 pixels image area

4. MATHEMATICAL MORPHOLOGY

Mathematical Morphology is based on set theory and applied in the study of object shape in an image (Russ, 1992). All complex object shapes can be decomposed into and represented by a number of basic structural elements. The two most common morphology operators are the Erosion and the Dilation operator.

Erosion operator is an area operator which removes pixel in the outermost boundary of an object region resulting in a smaller object. On the contrary, the Dilation operator adds an outer boundary layer, usually 1 pixel wide, to the existing region. In the example of a circular object such as a disc, the Erosion operator will reduce its area while the Dilation operator will increase the diameter of the disc.

5. DISCUSSION OF RESULTS

In order to evaluate the feasibility of these techniques to detect punctures in a geomembrane liner, a total of 41 holes of 4 different sizes were drilled at random locations within an area of 7″ long by 10″ wide on a piece of HDPE geomembrane liner. The four hole sizes are 1/8″, 3/32″, 1/16″ and 1/32″. A Canon Hi-8 video camera was used to record the surface conditions of the liner. The camera output was connected to a video digitizer of the Imaging Technology Series 151 image processor system where the captured video frame was digitized into a 2-dimensional image array of 512×480 pixels as shown in Fig. 3.

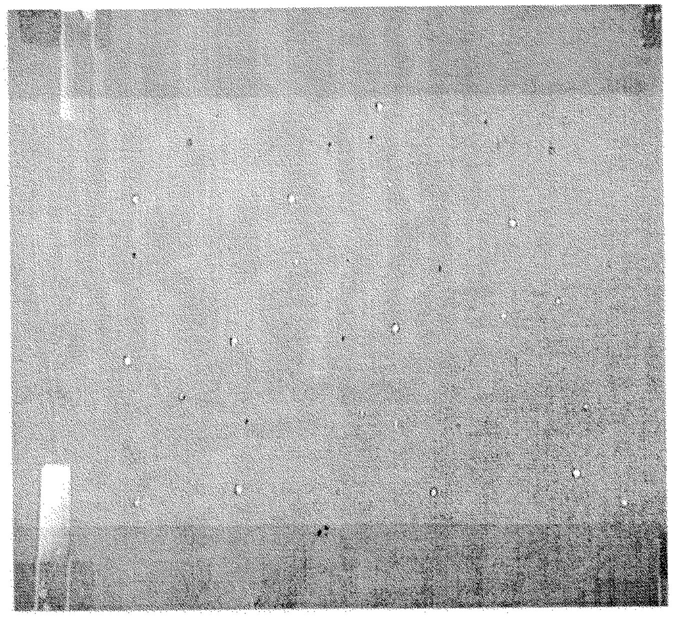

Fig. 3. Digitized image of the punctured geomembrane

The first image processing approach involves the use of the Sobel operator to increase the contrast of the pixels along the boundaries of the holes. A binary image is then obtained by simple thresholding where the light color represents the holes and the dark color represents the background as shown in Fig. 4. Table 1 summarizes the results of the detection rate of holes of different sizes. All but two holes were detected and further examination of the original image revealed a low contrast in gray level between the two undetected holes and their background.

Table 1 Detection Rate of Sobel Edge Detector

Hole Size	# of Holes Drilled	# of Holes Detected
1/8″	10	10
3/32″	11	11
1/16″	10	9
1/32″	10	9

The second approach employs the Dilation operator in mathematical morphology. The original image was processed by the Dilation operator repeatedly for 3 times to enlarge the size of the objects as shown in Fig. 5. Table 2 summarizes the processing results of this approach. Although the detection rate is shown to be identical to the Sobel operator in this particular experiment, one can easily observe that the increase in the hole size will reduce the ambiguity of the presence of smaller holes, thus give more consistent detection rate in the long run.

Table 2 Detection Rate of the Dilation Operator

Hole Size	# of Holes Drilled	# of Holes Detected
1/8″	10	10
3/32″	11	11
1/16″	10	9
1/32″	10	9

6. CONCLUSIONS

An innovative technique using image processing to detect construction flaws in a geomembrane liner was evaluated favorably in the laboratory. Punctured holes of diameter down to 1/32″ (0.8 mm) can be detected by the technique with a successful rate of higher than 90%. As the technique has been applied routinely by the Texas Transportation Institute to detect distress in highway pavement, the success in these laboratory experiments signals the high potential of successful applications of the technique to detect construction flaws in geomembrane liners in the field.

REFERENCES

Bass, J. M., Lyman, W. J., and Tratnyek, J. P. (1985) *Assessment of synthetic membrane successes and failures at waste storage and disposal sites*, U. S. EPA Report No. EPA-600/2-85/100, Cincinnati.

Gonzalez, R. C. and Wintz, P. (1987) *Digital image processing*, Addison-Wesley, Reading.

Koerner, R. M. (1990) *Designing with geosynthetics*, 2nd Edition, Prentice Hall, Englewood Cliffs.

Russ, J. C. (1992) *The imaging processing handbook*, CRC Press, Boca Raton.

U. S. EPA (1985) *Draft minimum technology guidance on double liner systems for landfills and surface impoundments - Design, construction, and operation (2nd version)*, Report No. EPA/530/SW-85/014, Cincinnati.

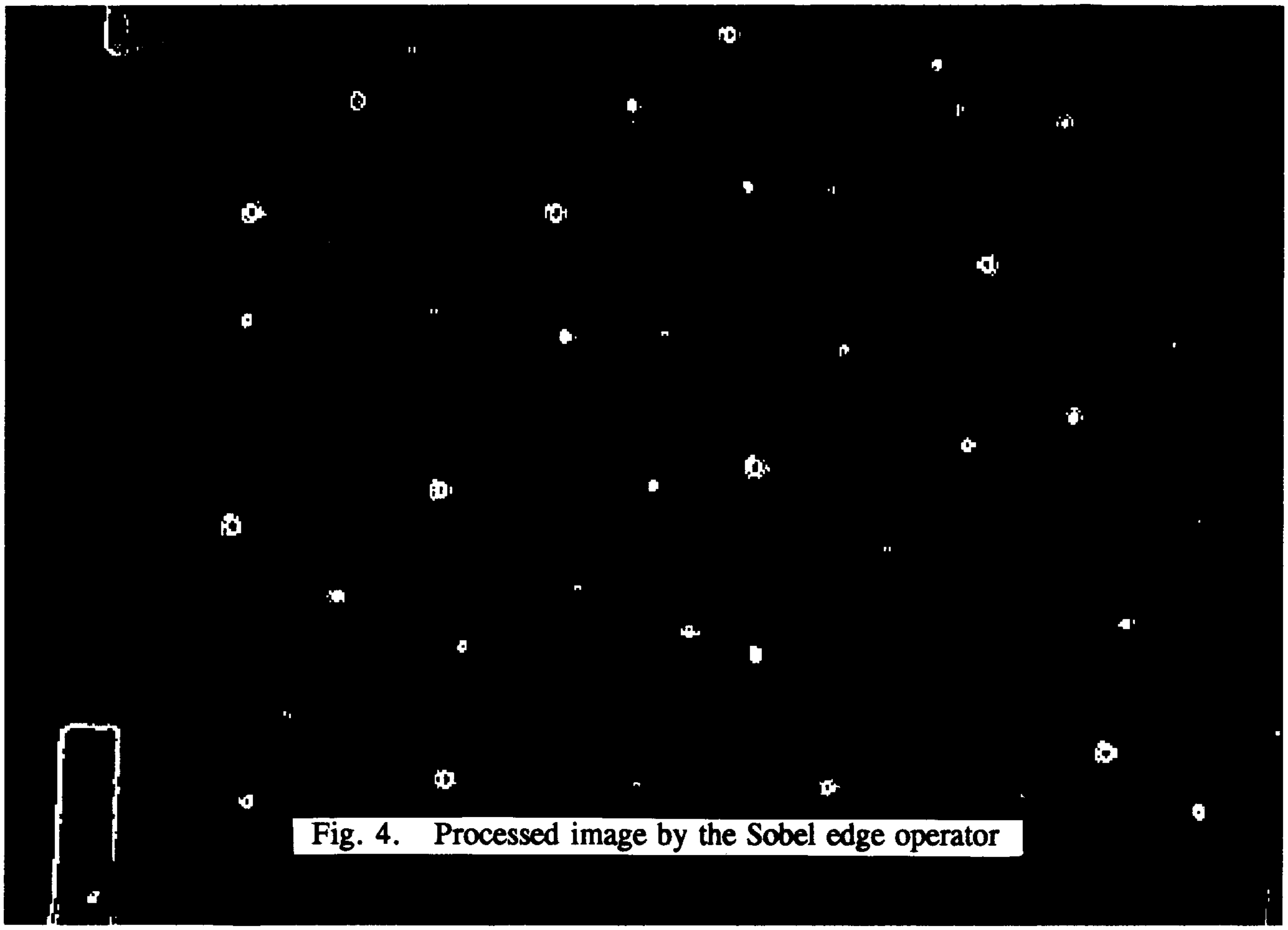
Fig. 4. Processed image by the Sobel edge operator

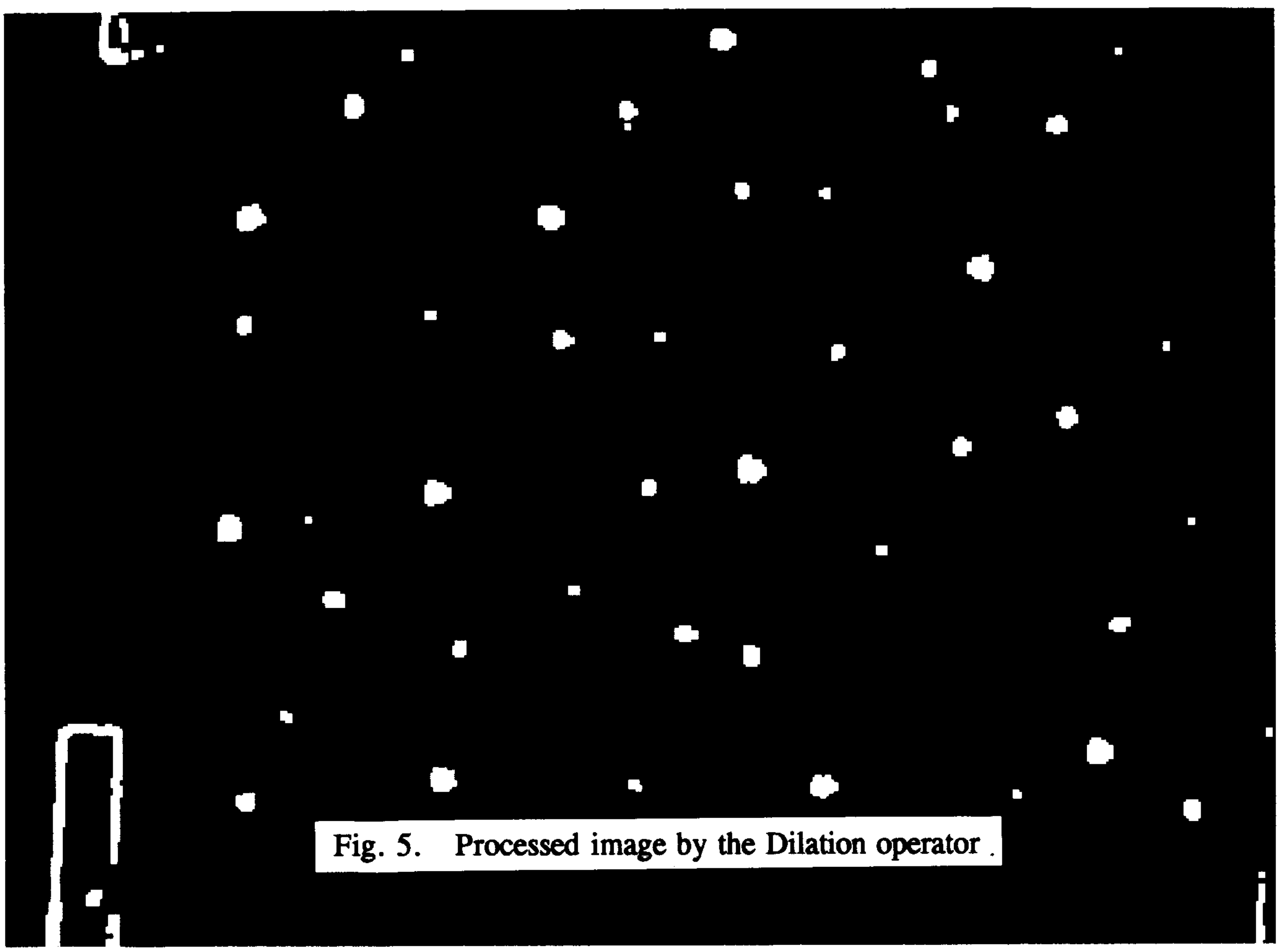
Fig. 5. Processed image by the Dilation operator .