A Practical Land Mine Detection Confirmation System Based on X-ray Lateral Migration Radiography

Zhong Su, Alan Jacobs, Edward Dugan, Chris Wells, Anthony Allard
University of Florida, Gainesville, Florida

Gary Carriveau
Science Application International Corporation, San Diego, California

ABSTRACT

X-ray lateral migration radiography (LMR), a Compton backscatter imaging method, has generated clearly recognizable images of surface-laid and buried land mines with a laboratory system and depth-of-burial less than 10 centimeters. Using two uncollimated and two collimated detectors to respectively register once-collided and multiple-collided backscattered photons, the image of a mine can be separated from the cloaking and confusion resulting from the soil surface and structure image. As a land mine detection confirmation system associated with a primary detection device, LMR can scan one square meter in about one-half minute. Laboratory acquired real mine LMR images display the mine air volume as a prominent feature, along with a less intense indication of the mine casing shape. Such images are not only unique to mine objects, but can often suggest sufficient detail for systematic land mine model identification. In addition to reviewing the LMR technique and laboratory results, this paper describes the details of an LMR system which can be fabricated using proven technology components. This system is to be mounted on a remote control vehicle as a confirmation sensor to a primary quick-scan device for field test employment. The LMR image acquisition, image processing/recognition and vehicle power (about 100 watts) systems are on the vehicle. The entire LMR system weight is under 250 pounds.

Keyphrases: lateral migration radiography, land mine detection, backscatter x-ray imaging

INTRODUCTION

A variety of methods have been used for detection of land mines. These range from simple hand-held metal detectors, which provide an audible indication when near to buried metal objects, to more elaborate systems using vehicular mounted arrays of metal detectors, ground penetrating radar, and various optical sensors. All of these techniques detect anomalies in the soil which might indicate the presence of a land mine; they are not specific to buried mines. These systems, independent of their sophistication, typically suffer from relatively high false alarm rates. There exists a great need for an inspection tool that can greatly reduce the false alarm rate without degradation of land mine probability of detection.

In late 1986, the University of Florida (UF) proposed that a particular variant of x-ray Compton backscatter imaging (CBI) be applied to the difficult problem of buried, plastic land mine detection. The CBI technique, first developed for medical applications [Towe & Jacobs, 1981], can produce high fidelity tomographic images of objects under study. However, it was clear early in the project that the method designed for medical and industrial applications was not directly applicable for mine detection. Specifically, the desired image data acquisition rate for land mine detection implied detection efficiencies that must be several orders-of-magnitude greater than previous CBI methods.

In response to this dilemma, a group at UF developed a totally new CBI approach [Campbell & Jacobs, 1992, Watanabe et al,1996, and Wehlburg et al, 1997] which is now called lateral migration radiography (LMR). This paper contains a brief description of LMR, it's application to confirmation of detection of land mines, and a conceptual design of a system which can be constructed with existing technology. We believe that LMR can provide the inspection tool that will reduce false alarms as well as making mine detection much safer and more cost effective.

This design is developed to be integrated with a remote controlled vehicle (RCV) which has ground penetrating radar as its prime search device and to perform real-world environment testing in land mine detection/confirmation.

LATERAL MIGRATION RADIOGRAPHY

The CBI system operates somewhat like an optical visual system, where photons are reflected from objects, detected and converted into an electrical signals, and processed to form an image. CBI techniques using x-rays have been successfully applied in commercial products, such as airport luggage scanning systems, COMSCAN tomography systems and developmental systems for functional imaging the heart.

All these CBI applications rely on first-scattered photons from the object under study to form images. Surface variations and structure can significantly influence the CBI image quality because these features can prevent/(aid) once-collided photons from/(in) reaching the detectors. Because of this effect, the CBI of an object with unknown surface structure does not uniquely separate image contributions from the surface and beneath. Slow-running computer algorithms are often necessary to extract useful information. Additionally, the dependence of a CBI system on first-collision backscatter photons to form images also imposes a constraint on detector size and collimation, mode of detector operation, and ultimately they yield very low efficiency detection. This limitation often leads to very high x-ray source strength and/or slow operation.

As the name suggests, lateral migration radiography effectively utilizes the lateral transport of multiple-scattered photons to form images. Large area detectors, correctly positioned and collimated, allow extraordinary reductions in the required x-ray source strength and the image acquisition time. LMR systems typically use two sets of detectors to form images. One set of uncollimated detectors respond predominately to first-collision photons; a second set is collimated and placed so as to sense multiple-collision photons. The uncollimated detectors produce intense images of the surface features. The contrast in the collimated detector images is due to multiple-scattered photon lateral transport that is sensitive to the electron density of the transport medium as well as the surface spatial details. This enables one to image buried objects that contain internal variations in electron density and identify such differences.

The multiple-collision photons always carry information from the first collision. However, with the increase in the number of collisions, multiple-collision components average out random electron density variations while retaining the information from the structural details. Because LMR images are not restricted to first-scatter photons, this approach is very useful for imaging objects in the presence of surface structure which ordinarily would cloak the image of subsurface variations.

LAND MINE DETECTION/CONFIRMATION/IDENTIFICATION

The UF landmine detection imaging system consists of a pair of uncollimated detectors placed near the source beam and another pair of detectors with lead collimators located adjacent to these uncollimated detectors but farther from the x-ray beam. The particular configuration employed to acquire the images presented herein is shown in Figure 1. To generate an image the x-ray beam should raster in the gap between the two uncollimated detectors and also move with the detectors in a direction orthogonal to this raster direction. However, in the existing image acquisition system, the x-ray beam remains stationary and a large soil box in which the mines are buried moves in the two orthogonal directions. This type of ground illumination was necessitated in the UF image acquisition system because of constraints of the previously available x-ray generator (a 1950 vintage GE Maxitron 300).

Figure 2 is a concept drawing illustrating an LMR mine imaging system which can accomplish the necessary motions of an illumination x-ray beam. It is the system which is to be attached to the RCV for two modes of operation: 1. As a single-modality land mine detection device for swaths one to three meters wide. 2. As a multi-detection-modality component employed to confirm land mine presence in a small region selected by a fast-scan modality.

The results of LMR imaging of three plastic buried land mines (M19 and TMA-4 antitank, and TS/50 antipersonnel) are included herein as Figures 3-6. These images are part of the output of measurements in which LMR was used to image twelve types of actual, buried land mines that were provided by the U.S. Army. The acquired images demonstrate that detection is possible with burial depth ranging from on the soil surface to 10 centimeters. Moreover, the images are so definitive that clear identification of mine-type can be accomplished. When combined with the exterior mine shape, interior air volume (due to fuse wells) offer vivid, unique signatures. It is recognized by all investigators, in the pursuit of buried land mine detection approaches, that the prohibitively high-rate of false alarm positives is the remaining completely-limiting problem. The LMR technique, for near surface buried mines, clearly does not suffer from that limitation.

In each of Figure 3-6, the caption includes LMR imaging parameters, burial condition and salient image signature features. It should be emphasized that the crucial, high-intensity LMR image regions in these figures are generated by the mine-interior air volumes, not the mine surface, and that these intense signatures are the clear and unique identifiers of: 1. The presence of a buried land mine. 2. The specific land mine-type.

Using a current technology x-ray generator (LORAD 200), LMR images of a 30 cm diameter simplistic, simulated plastic mine with an included 14 cm diameter air volume have been acquired. The simulated mine is buried at 3 cm and 5 cm depths with surface clutter and without surface clutter. The presence of mine image cloaking generated by the surface clutter is evident in Figures 7 a, b and e, and Figures 8 a, b, and e. The effect of application of image processing using collimated/uncollimated image subtraction followed by either Fourier filtering or front/rear collimated detector image subtraction to enhance the mine image are presented as Figures 7 c, d, f, g and h, and Figures 8 c, d, f, g and h. Captions for these figures describe the situation in more detail.

Figures 9 a and b illustrate the sensitivity to soil density of mine imaging capability using LMR. Figures 9 a and b are the LMR image results respectively acquired in a measurement of the 30 cm diameter mine simulant at a burial depth of 7.6 cm in 1.6 g/cc soil and predicted by a Monte Carlo numerical experiment of the same situation with a similar mine but soil of density 1.1 g/cc. In Figure 10 is shown the x-ray mean-free-path for a 150 kVp x-ray spectrum for various soil type. The soil density variations used imply a factor of about 5 decrease in signal for a burial of 7.6 cm. This explains the loss of apparent mine image in the acquired case here presented.

PROPOSED LMR MINE DETECTION/CONFIRMATION SYSTEM

Primarily because of the large area detectors used in LMR, relevant information-carrying photon detection efficiencies are sufficiently high that the resulting electric energy requirement for x-ray generation is only one joule per acquired image pixel. Presuming two square centimeter image pixel yields an x-ray generator power requirement of 140 watts for an interrogation rate of 100 square meters per hour with an implied pixel dwell time of about seven milliseconds. The following description of a system and performance specifications are based on the above presumption.

The identified x-ray tube in Figure 2 is the output diode of a typical industrial inspection x-ray generator (e.g. LORAD 160) with a constant potential of 160 kilovolts and 140 watts power capacity. To scan the soil (in the herein-designed raster direction) a continuously-rotating cylindrical collimator is illustrated. For the illustrated x-ray tube focal spot 1.5 meters above the soil surface, the maximum scan angle of 37° covers a raster scan of one meter on the soil surface yielding a maximum x-ray beam incidence angle of 18.5° to the vertical. Incidence angle of less than 20° cause predictable and easily-corrected LMR image distortion.

During either of the two mine imaging modes, the RCV remains stationary during image acquisition. If employed in Mode 1.n, the herein-designated motion direction is provided by stepping in the illustrated LMR system carriage two centimeters following each one meter raster scan for a total of 50 steps (i.e., one meter of motion direction movement, or equivalently, one square meter of interrogated soil surface). The LMR system carriage is then stepped one meter in the raster direction followed by a total of 50 two centimeter steps in the (reverse) motion direction (i.e. two square meters of adjacent soil surfaces interrogated). Another one meter LMR system carriage step in the raster direction followed by 50 two centimeter motion direction steps yields three square meters of adjacent soil surfaces interrogated. The “n” in the Mode 1.n refers to the number of LMR system carriage steps in the raster direction. Thus, n=1,2,3 implies respective interrogated swath widths of 1,2,3 meters. Following n carriage steps the RCV is moved forward one meter and the process is repeated.

If employed in the mine-confirmation mode, Mode 2, sites of interest are identified according to location and estimated size (e.g., 10 centimeter diameter for an antipersonnel mine, and 30 centimeter diameter for an antitank mine). The RCV is then positioned such that the LMR system carriage can be centered on the identified site. One of two rotating collimators is chosen such that either a 20 or 60 centimeter raster scan is illuminated on the soil surface. The motion direction scan is selected to match the raster scan such that respectively a 400 or 3,600 square centimeter region is interrogated (i.e., a 200 or 1,800 pixel image centered on the suspected mine).

Detector signal digitalization and image pixel assignment are synchronized to the constant-frequency rotation of the x-ray source collimator cylinder. The backscattered x-ray field detectors are light-weight versions of the plastic scintillators currently employed in the UF laboratory. Several miniature photomultiplier/amplifier/bias-voltage-supply assemblies are the signal amplification and output devices for each plastic scintillator. All components are readily available or fabricated. In addition to the illustrated hardware components, the system requires all computer hardware and software to acquire, store and scroll-display image data, as well as the algorithms to remove mine image cloaking features, recognize a mine object, and identify mine-type.

The LMR image acquisition times for particular examples of Mode 1.n and 2 applications, based on the described system, and a pixel area of two square centimeters, are:

Mode	Swath width	Swath length	Region size	No. pixels	Image time
1.3	3 m	20 m	-	3x10	0.6 hr
1.3	3	100	-	1.5x10	3
1.2	2	20	-	2x10	0.4
1.2	2	100	-	1x10	2
1.1	1	20	-	1x10	12 min
1.1	1	100	-	5x10	58
2	-	-	20x20 cm	200	1.4 sec
2	-	-	60x60	1,800	12.6

The individual pixel x-ray illumination dwell time of seven milliseconds translated into the easily attainable collimator rotational speed about 12.5 rpm. Most LMR image enhancement algorithms involved the scaling and /or summing of images acquired by various detectors in the array and/or retrieval and use of archived mine-type images. With dedicated computer design, such manipulations will add little time to the above acquisition increments for enhanced-image display.

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