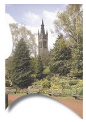
Sengodan, A., and Cockshott, W.P. (2012) *The SIMCA algorithm for processing Ground Penetrating Radar data and its use in landmine detection.* In: Set for Britain, 12 March 2012, London, UK

The *SIMCA* algorithm for processing Ground Penetrating Radar data and its use in landmine detection.

Mr. Anand Sengodan and **Dr. W. Paul Cockshott**

Computer Vision and Graphics Group, School of Computing Science, Lilybank Gardens, University of Glasgow, Glasgow G12 8QQ, UK

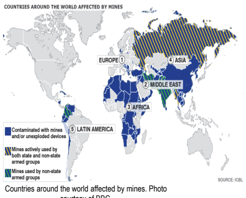


Introduction

- Landmines and improvised explosive devices ('IEDs') pose a serious threat to civilians in many countries.
- Ottawa Treaty stipulates countries have to clear the landmine stockpiles.
- Unfortunate death of UK military personnel in Afghanistan and Iraq. Most of the casualties has been caused by IEDs.

Landmine statistics:

- 85 to 90 million landmines currently scattered in 62 countries [1].
- In 2009, there were 7,288 attacks in Afghanistan, a 120% increase over 2008, and a record for the war [1].
- 209 UK military deaths out of the total of 397 were caused by IEDs [2].



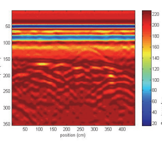
Countries around the world affected by mines. Photo courtesy of BBC.

Sample landmines.

Method of study

- Ground Penetrating Radar('GPR') is non-destructive geophysical technique that uses radio waves to probe the "ground".
- Transmitter and receiver in a fixed geometry are moved over the surface to detect the reflections from landmines.
- Computer image processing techniques on GPR data can be used to detect the location of landmines.
- GPR images are typically hard to interpret being full of artifacts produced by the imaging modality.
- GPR images contain artifacts because of interference caused by interactions between the ground and the antenna, soil reflections, major antenna effects from the GPR signal and clutter.
- As a result the images contain a lot of curved lines and are difficult to interpret.
- Current techniques do not successfully remove the artifacts and this calls for a technique which is able to help the deminer to predict the location of the landmine more accurately.

Cobham's MINEHOUND™ equipment



Raw GPR scan

SIMCA algorithm

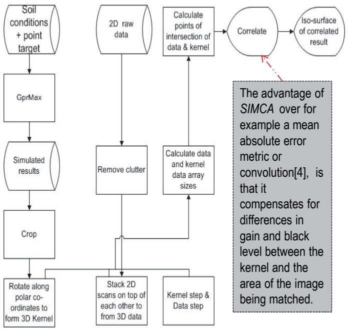
- ***SIMCA*** ('***SIM****ulated* ***C****orrelation* ***A****lgorithm*') is a technique based on an area correlation between the trace that would be returned by an ideal point reflector in the soil conditions at the site and the actual trace.
- Trace that would be generated by the ideal point reflector is generated using *GPRMAX2D v1.5*; an electromagnetic simulator for GPR using the systems aspects of the radar and the soil properties. This allows the derivation of the 2D kernel(or filter) and subsequently the 3D kernel is formed by rotating the 2D kernel along the polar co-ordinates.
- *SIMCA* then takes the raw data as the radar is scanned over the ground and removes the clutter such as cross talk and initial ground reflection [3].
- *SIMCA* then using area correlation compares the ideal point reflector trace with the actual traces and from this it works back to the collection of objects that might have generated the observed traces.
- For the 3D case, the second phase of the algorithm involves performing a volume correlation between the 3D kernel and the 3D data to yield a volumetric correlation potential. This volumetric potential can then be visualised using isosurfaces.

SIMCA continued

- The Pearson's correlation coefficient between two variables is used which is defined as the covariance of the two variables divided by the product of their standard deviations:

$$\rho_{X,Y} = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y}$$

- As a contrast enhancing phase the correlation array was raised to the power of 3, as this raising enhances the target/background separation.
- Using *ParaView* software the correlated slices are loaded up and using an level of threshold the 3D isosurfaces are created. *ParaView* is a open-source application for the visualization/analysis of scientific data sets.
- Kernel is a small matrix of pixels, that emphasizes a particular feature of the image.



Flowchart of *SIMCA* 3D algorithm

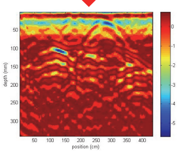
Results 2D

- The experimental data source used to obtain the GPR data from which the following results were obtained is detailed in another paper by the author [3].
- The *SIMCA* algorithm was compared with conventional Convolution [4].
- Results indicated that the *SIMCA* technique outperformed Convolution. This was both in terms of speed and in locating the landmine.
- Results are also good considering the profile of the relevant detail in the hyperbolic kernel is more horizontal than vertical.

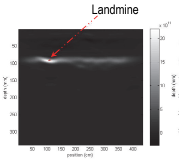
Survey using GPR equipment

Raw Data from GPR equipment

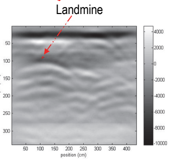
Process GPR data



Clutter removed processed GPR data



SIMCA Correlation



Conventional Convolution

Performance of *SIMCA* compared with conventional Convolution

	Length of target (mm)	Depth of burial (cm)	Processing time (s)
Ground truth	115	10.2	-
SIMCA	112	9.5	0.8
conventional Convolution	106	9.1	1.9
Error in *SIMCA*	2.6%	6.9%	-
Error in conventional Convolution	7.8%	10.8%	-

Results 3D

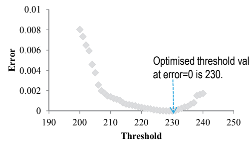
- The reasons for using a 3D approach is because a 3D approach has more sampling points compared to a 2D technique and a 3D isosurface enables both the shape, volume and dimensions of object to be assessed.

Results 3D continued

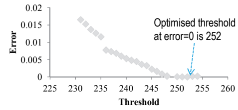
- The optimised threshold level for each method was calculated by firstly selecting one of the landmines in each case to be the training set. For this training set the threshold was varied using a binary search approach and the volumetric error calculated using:

$$error = \left(\log\left(\frac{v}{t}\right)\right)^2$$

  where v is the volume of the landmine found at that threshold using the *ParaView* software and t is the true volume of the actual landmine.
- Using the optimised threshold for each case the reconstruction of the volumes of real targets after scanning by a GPR was carried out.



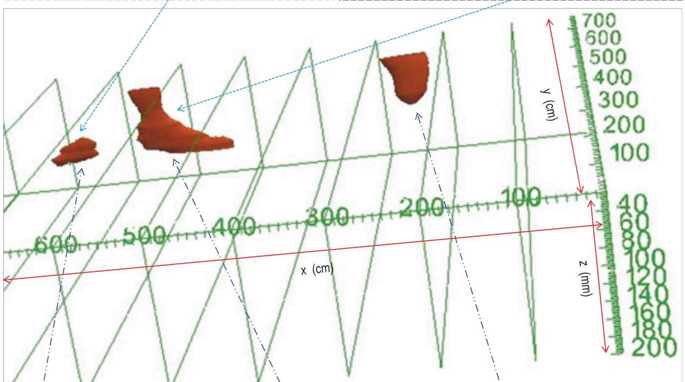
Graph for *SIMCA* method



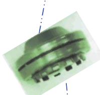
Graph for conventional ***Convolution method***

I. Another study proved that users who had no experience of locating targets were able to locate these targets after processing by *SIMCA* algorithm [3].

1. ***SIMCA*** **algorithm is considerably more accurate in displaying plastic landmines which are one of the main problems in landmine detection.**
2. ***SIMCA*** **algorithm reproduces the wooden handle of the pistol much more accurately than the conventional Convolution algorithm.**



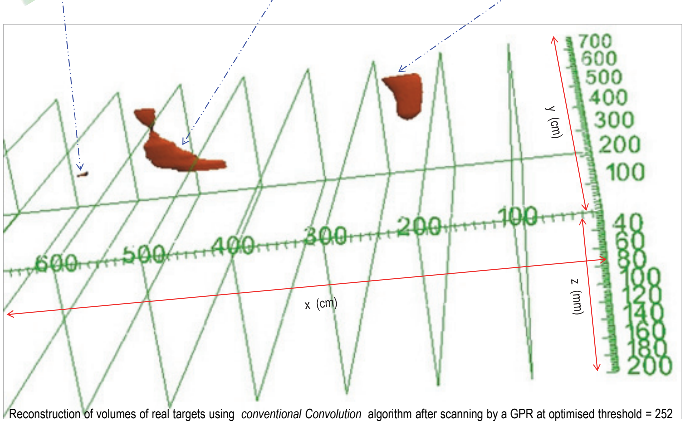
Reconstruction of volumes of real targets using *SIMCA* algorithm after scanning by a GPR at optimised threshold = 230



Plastic MAUS mine [567,310,51]
Height = 46 mm
Diameter = 89mm

Pistol with wooden grip casing [476,350,49]

Metallic M26 [210,430,49] mine
Height = 145mm
Diameter =79mm



Reconstruction of volumes of real targets using *conventional Convolution* algorithm after scanning by a GPR at optimised threshold = 252

Performance of *SIMCA* compared with conventional Convolution

	Volume of plastic MAUS mine (cm^3)	Volume of Pistol (cm^3)	Volume of metallic M26 mine (cm^3)	Processing time (s)
Ground truth	286	500	711	-
SIMCA	280	491	698	0.9
conventional Convolution	57	380	590	1.8
Error in *SIMCA*	2.1%	1.8%	1.8%	-
Error in conventional Convolution	80.1%	24.0%	17.0%	-

Novelty of *SIMCA algorithm*

- Use of Correlation, use of the systems aspects of the radar and the soil properties and raising the brightness to an odd power >2.
- In imaging processing, area correlation can give sub-pixel accuracy in locating the source of targets [Siebert et al [5],chapter 6,section 6.6 pp.238].
- Faster than existing techniques and better results in terms of locating landmines.
- Considers case when spatial separation between A scans(1D array of returned energy readings indexed by time) that make up a 2D profile is typically smaller than, and not always an integer multiple of the spatial separation between the 2D profiles that make up the 3D profile.

Conclusion

- ***SIMCA*** algorithm is therefore a novel method of helping the demining personnel predict the location of landmines with acceptable degrees of accuracy.
- ***SIMCA*** outperforms convolution for the landmine data.
- ***SIMCA*** algorithm will help reduce the number of deaths and also enable more of the land to be put to good use.

References

1. International campaign to ban landmine, 2011. URL: http://www.icbl.org.
2. BBC News Website, 2012. http://www.bbc.co.uk/news/uk-15188729.
3. Sengodan, A. and Javadi, A. "Landmine detection using masks on Ground Penetrating radar images", *IRIS 2005.*
4. *Scheers, B., Acheroy, M., Vorst A., "Migration technique based on the time-domain model of the Ground penetrating radar", Proc. SPIE, vol. 4491, pp. 111-119, Nov. 2001.*
5. Siebert, P.J, and Boguslaw, C. " An introduction to 3D computer vision techniques and algorithms". *John Wiley and Sons Inc,* Dec. 2008.