A 3D reconstruction algorithm for the location of foundations in demolished buildings

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Abstract—**The location of foundations in a demolished building can be accomplished by undertaking a Ground Penetrating Radar (GPR) survey and then to use the GPR data to generate 3D isosurfaces of what was beneath the soil surface using image reconstruction. The *SIMCA* ('*SIMulated Correlation Algorithm'*) algorithm is a technique based on a comparison between the trace that would be returned by an ideal point reflector in the soil conditions at the site and the actual trace. During an initialization phase, *SIMCA* carries out radar simulation using the design parameters of the radar and the soil properties. The trace which would be returned by a target under these conditions is then used to form a kernel. Then *SIMCA* takes the raw data as the radar is scanned over the ground and removes clutter using a clutter removal technique. The system correlates the kernel with the data by carrying out volume correlation and produces 3D images of the surface of subterranean objects detected. The 3D isosurfaces are generated using MATLAB software. The validation of the algorithm has been accomplished by comparing the 3D isosurfaces produced by the *SIMCA* algorithm, *Scheers* algorithm and *REFLEXW* commercial software. Then the depth and the position in the *x* and *y* directions as obtained using MATLAB software for each of the cases are compared with the corresponding values approximately obtained from original Architect's drawings of the buildings.**

Index Terms—**GPR; simulation; kernel; correlation; convolution.**

I. INTRODUCTION

It is the aim of this paper to present the 3D reconstructed isosurface produced by the *SIMCA* algorithm and compare them to 3D isosurface obtained using the *REFLEXW* software. Also the same data is going to be processed using the *Scheers*' algorithm [2]. Then the objectives of this study was to acquire data from a car park which was built on the former site of a row of 19th century terraced houses, to process the data using the above mentioned techniques and then finally validate the results. The existing car park shows bumps, cracks and there is the irregular subsidence of the tarmac surface due to the effects of the structural remains of the demolished houses that occupied the site prior to the car park construction.

Photographs of the original terraced buildings along with the degrading car park are shown in Figures 1 and 2 respectively. The resulting 2D radargrams produced by the *SIMCA* algorithm are given in [1] and from *https://sites.google.com/site/simcaforfoundations/*.

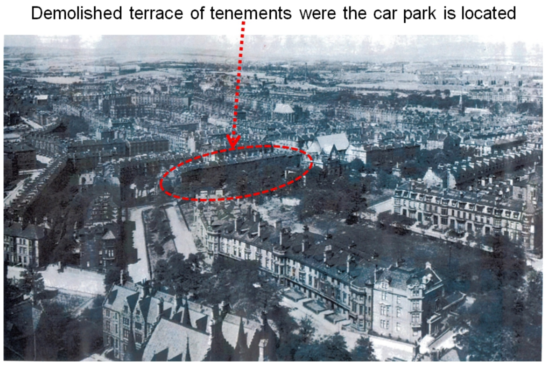

Fig. 1. Photograph showing location of demolished buildings (Courtesy of T. R. Annan and Sons).

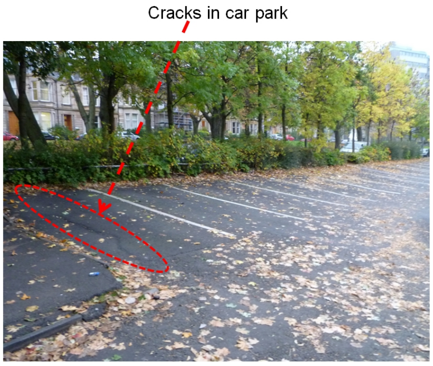

Fig. 2. Photograph showing the crack in the car park.

The background to the site and the data acquisition procedure are detailed in [1].

GPR traces contain a lot of artifacts such as the noise produced by near surface clutter (e.g. demolition debris) and also clutter such as cross talk, initial ground reflections and antenna ringing and prevent the accurate estimation of the position of targets. Therefore a clutter removal technique used by the *SIMCA* algorithm is detailed in [1].

Figure 3 shows the raw and the processed radargrams. From these figures it is difficult for a untrained operator to locate the foundations. Therefore it can be concluded that it would be easier for an operator to understand and locate the foundations from 3D isosurfaces.

II. *SIMCA* ALGORITHM

The flowchart of the *SIMCA* algorithm is shown in Figure 4.

Using a point based target and the properties of the soil at the site, the *SIMCA* algorithm carries out GPR simulation and from this simulated result the 2D correlation kernel is derived. By rotating the 2D kernel along the polar co-ordinates produces the 3D kernel. *SIMCA* then takes the raw data as the radar is scanned over the ground and removes the clutter such as cross talk, initial ground reflection and antenna ringing. This clutter is removed by computing the mean vector of a number of scans and then to subtract this from each of the scans. This produces the clutter removed 2D radargram. The 3D data can be then formed by the stacking of the clutter removed 2D radargram.

The *SIMCA* technique then carries out volume correlation between the ideal point reflector trace generated by carrying out GPR simulation using *GprMAX2D v1.5* developed by [3] and the clutter removed GPR trace obtained in the field. Then raising the image to an odd power >2 enhances the target/background separation. We use Pearson's correlation coefficient between two variables which carries out division between the covariance of the two variables and the product of their standard deviations.

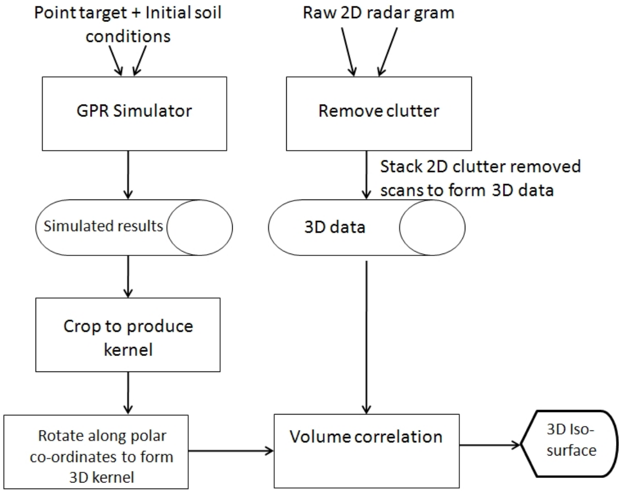

Fig. 4. The flowchart of the *SIMCA* algorithm.

Figure 5 shows the 3D reconstructions obtained using the *SIMCA 3D* algorithm. What can be noticed in the figure is the *SIMCA* algorithms ability to reconstruct the remnants of the remains of the former foundations in the demolished building. The cracks in the car park also correlate well with the remnants.

III. SIMULATIONS CARRIED OUT TO DEVELOP KERNELS

The GprMAX2D program is a GPR simulator which allows for the derivation of the kernel. The simulator uses finite-difference-time-domain (FDTD) method to solve Maxwell's equations. The program takes a data file as input containing the soil conditions, the domain size, the discretization step, the time window, the details of the buried object, the details of the GPR and the location of the transmitter and receiver. In order to run the simulations, a 0.025m radius sphere is buried in the same soil conditions as those in the car park is used and then the GPR simulation is run.

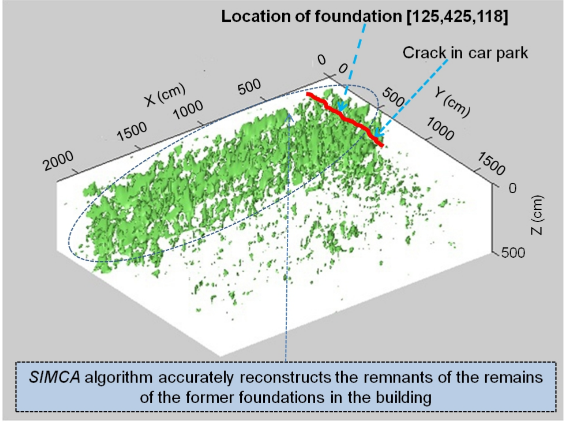

Fig. 5. 3D isosurface produced using the *SIMCA* method. Isosurface produced at isosurface level = 0.02.

IV. *Scheers'* ALGORITHM

The *Scheers et al's* migration by deconvolution method [2] is the best alternative system reported in the open literature. In the *Scheers* method a synthetic C scan of a small point scatterer is determined by forward modeling. This 3D point spread function has the system characteristics such as the waveform of the source, the antenna footprint and the IR of the antenna. This 3D point spread function is used to deconvolve the recorded B scan. *Scheers'* uses the Weiner filter [4] to deconvolve the point spread function out of the recorded data. In order to produce the 3D isosurfaces we implemented the Scheers' algorithm and the resulting isosurface produced for the Scheers algorithm is from this implementation.

Figure 6 shows isosurfaces reconstructed using the *Scheers* method. What is noticed here is that the *Scheers'* algorithms inability to reconstruct the remnants as successfully as produced by the *SIMCA* algorithm. Also the remnants' reconstructions as shown by the cracks have not been accurately reconstructed.

V. ACQUIRING OF THE DATA

The area of the GPR survey was 47.75 square metres and was carried out in the NE portion of the car park. A PulseEKKO 1000 GPR system was used and the system had a high frequency antenna of 450 MHz. A common offset reflection mode was used which had a antenna spacing of 0.25m. To allow for correct antenna positioning a reference tape measure was located along each of the GPR profiles. The line spacing used was 0.5m and an inline spacing of 0.05m was used.

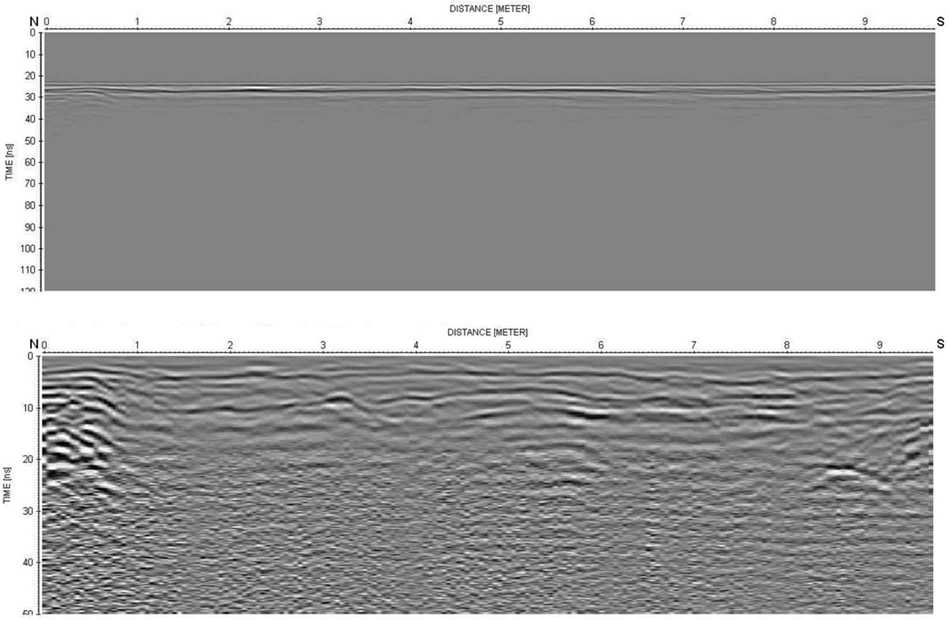

Fig. 3. The 2D radargrams. The figure on the top is the unprocessed raw radargram and the one on the bottom is the clutter removed radargram.

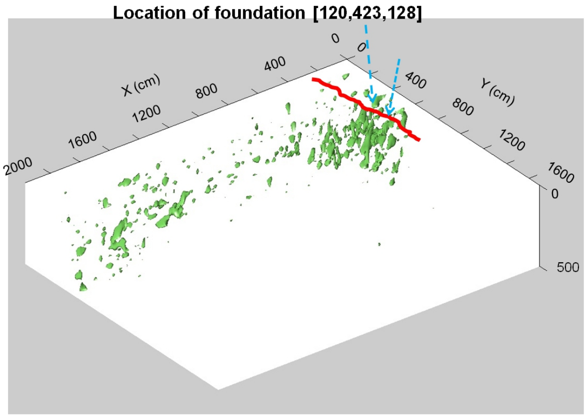

Fig. 6. 3D isosurface produced using the *Scheers* method. Isosurface produced at isosurface level = 0.09.

VI. PROCESSING USING *REFLEXW* COMMERCIAL PACKAGE

The processing step used to process data using the *REFLEXW* commercial software is detailed in [1]. A 3D block was constructed from the parallel profiles and then the 3D reconstructed isosurface was generated from this as shown in Figure 7. Table I illustrates the processing steps used to process the data using the REFLEXW software. Attenuation in the ground is compensated by a varying gain in the receiver part of the system.

TABLE I
THE PROCESSING STEPS USED IN THE REFLEXW SOFTWARE

	Processing steps
1	Static correction
2	Subtract-mean (dewow)
3	Gain (energy decay)
4	Background removal
4.1	Time cut

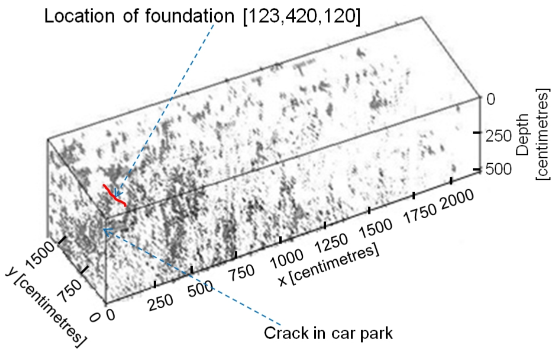

Fig. 7. Isosurface generated using *REFLEXW* commercial software at threshold of 0.02.

VII. COMPARISON OF RESULTS

Table II gives the values for the x-position, y-position and the burial depth for the ground truth and those from the three methods. The actual values for the above parameters are obtained from Architects drawings. The percentage errors indicate that the *SIMCA* algorithm is slightly better than the REFLEXW software and that the *Scheers* algorithm again is not accurate. This shows that the *SIMCA* algorithm is accurate in reconstructing targets. The absolute errors for the x-position and the burial depth for the *SIMCA 3D*, *Scheers* algorithm and the REFLEXW software are better than the corresponding results obtained using 2D methods, but overall the *SIMCA 3D* algorithm produces better results in comparison to the other two techniques.

The values of the percentage errors for the values obtained in the table below for the *SIMCA* algorithm are really good when considering the various error sources which cause the value of the above parameters attained from Architect drawings to be not accurate. The various error sources in values obtained for the parameters from the Architects drawings are now discussed in the next section.

TABLE II
ACTUAL POSITION IN THE x-DIRECTION, ACTUAL POSITION IN THE y-DIRECTION, ACTUAL BURIAL DEPTH AND CORRESPONDING VALUES PRODUCED BY THE *SIMCA* ALGORITHM, *Scheers* ALGORITHM AND THE *REFLEXW* COMMERCIAL SOFTWARE. THE TABLE ALSO GIVES THE PERCENTAGE ERROR FOR THE THREE METHODS WHEN COMPARED TO THE GROUND TRUTH. THE POSITIONS IN THE x AND y DIRECTIONS ARE IN CENTIMETERS AND THE DEPTH IS IN CENTIMETRES.

	x-position *cm*	y-position *cm*	depth *cm*
Ground truth	139	440	108
SIMCA	125	425	118
Scheers'	120	423	128
REFLEXW	123	420	120
Error in *SIMCA*	10.1%	3.5%	9.5%
Error in *Scheers'*	13.7%	3.9%	18.5%
Error in *REFLEXW*	11.5%	4.5%	11.1%

VIII. ERROR SOURCES IN ATTAINING VALUES OF PARAMETERS OF THE GROUND TRUTH FROM ARCHITECT'S DRAWINGS

It is to be noted however that an accurate location of the actual foundations can only be obtained and then the results compared with the construction plans by excavating the car park and locating the foundations. This is not feasible and only a rough estimate can be attained for these circumstances. Also whilst comparing the values of the position in the x direction and the burial depth from the Architect drawings it can be noted from Figure 8 that an accurate estimate of the above values cannot be attained from the Architect drawings because:

- During the laying of the tar the construction team made lots of errors in laying the actual foundations and the values of the burial depth and the position in the x direction is not achieved in reality. It also happens in some cases that to economise the cost of the project the construction teams save on concrete and thus the above values are also not achieved.
- The actual foundation could have weathered and settlement of the foundations might have occurred over time and this will cause errors in the values of the parameters.
- Some of the foundations might have been removed to make way for the car park.
- Some discrepancies in the measurement campaign by our survey.

All the above errors accumulate and thus the final value of the burial depth and the position in the x direction obtained from the Architect drawings are not accurate. Thus it is not possible to calibrate the *SIMCA* algorithm and to validate the values of the above parameters and to estimate the error of the algorithm. Therefore a discrepancy will exist between the readings obtained from the *SIMCA* algorithm and an accurate estimate can only be attained by excavating the car park and looking for the foundations.

IX. CONCLUSION

Therefore the *SIMCA* algorithm can be provided to non profit organizations as freeware and is validated by a well-established but rather expensive commercial tool such as *REFLEXW*. The *SIMCA* algorithm also produces clearer reconstructions of the foundations in comparison to the *Scheers'* algorithm. The authors have also tested the *SIMCA* algorithm on the location of landmines [5]. Furthermore 3D techniques have advantages over the 2D technique developed in [1]. Such advantages include the accurate derivation of the dimensions of the target and the fact that such volumetric displays allow the practitioner to visualize the data volume in its entirety using a single volume.

ACKNOWLEDGMENT

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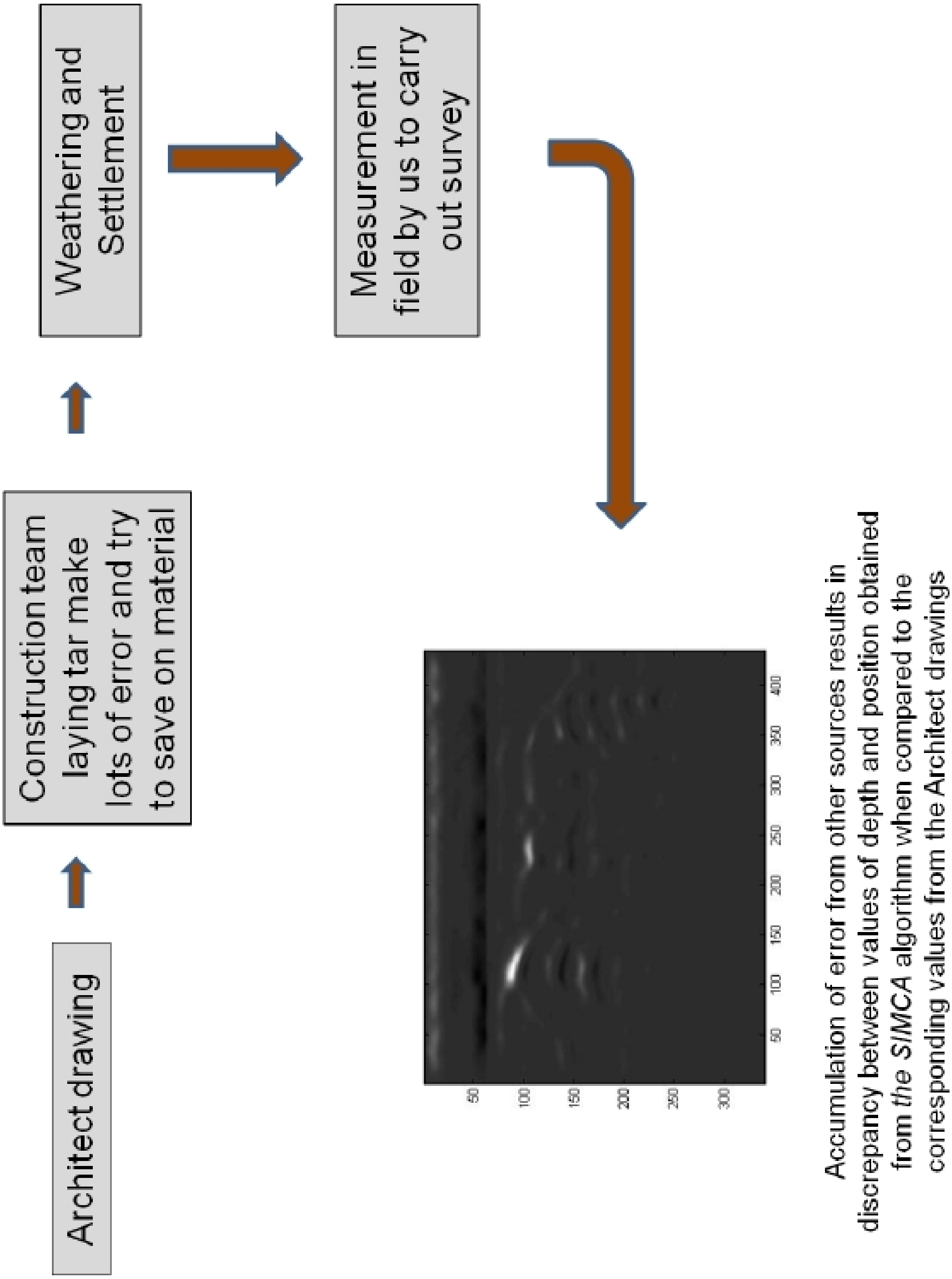

Fig. 8. Sources of error in the values of the ground truth parameters as obtained from Architect's drawings.