AN INTEGRATED APPROACH TO DETERMINE PARAMETERS OF A 3D VOLCANO MODEL BY USING INSAR DATA WITH METAMODEL TECHNIQUE

Hao Zhang[1], Xiaoying Cong[2], Michael Eineder[3], Kai-Uwe Bletzinger[1]

1. Structural Analysis, Technische Universitaet Muenchen, Germany
e-mail: h.zhang@bv.tum.de, kub@bv.tum.de

2. Remote Sensing Technology, Technische Universitaet Muenchen, Germany
e-mail: debra.cong@bv.tu-muenchen.de

3. German Aerospace Center (DLR), Remote Sensing Technology Institute, Germany
e-mail: Michael.Eineder@dlr.de

ABSTRACT

In this paper, an integrated approach is presented to determine the suitable parameters of a magma-filled dyke, which causes observable deformation at the ground surface. By this approach, the finite element method (FEM) and metamodel techniques are combined. FEM is used to establish the numerical model of the dyke and to produce the data required to identify metamodel parameters. Parameter identification problems are also known as parameter estimation or inverse problems. The metamodel technique is employed to make the whole procedure efficient in the identification phase. The identification approach is carried out by a systematic routine based on particle swarm optimization (PSO) algorithm. The approach is tested with synthetic data generated by analytic models. Moreover, it has been also applied to Stromboli Volcano (Italy) as an example, and the ground deformation data is acquired by using interferometry SAR technique. With the approach, the parameters can be successfully estimated with acceptable degree of accuracy. The results also indicate that only one kind of geophysical data are not sufficient for solving such a complex problem.

Keywords: inverse problem, InSAR, finite element volcano model, metamodel technique, PSO

1. INTRODUCTION

Parameter identification is a common but very important task in the world of science and engineering. Basically, it means to find a proper set of parameters of a model, to be well fitted, to a given data set. [1] In this paper, we deal with a mechanics based model of a magma-filled dyke and its parameters. They are to be identified, by observing the deformation at the ground surface which is measured with SAR data by using interferometric technique. In order to better understand the deformation pattern and the related mechanical behavior, a model is needed. In many literature references [2], the analytical model given by Okada [3] was used for the purpose of simplification. Although it has been proven that the Okada model can predict reasonable deformation [4], it only works for a dislocation located in isotropic homogenous medium. Instead, we propose to apply a finite element model. In principle, many features such as inelastic material, heterogenous structure [5] and effects of topography [6] can easily be realized by additionally available information. During the identification phase the FE model appears to be inefficient to serve as deformation model which should be run many times to find the parameter set best matching the simulated data with the measured deformation data. To overcome the efficiency issue, the possible way is to use a simpler model instead. We modified the direct approach by introducing the idea of metamodel technique. The basic idea of our approach is to train a metamodel, more specifically a Kriging model [7], by the help of the FE model. Then we use the trained metamodel to replace the FE model in the optimization procedure to identify the parameters. With this approach, the total amount of calculation time is much reduced. At the same time, since the metamodel has a good approximation to the original model, the strengths of the FE model are maintained. It has to be mentioned that the problem is a highly nonlinear one. To avoid the drawbacks of possibly present local minima, the Particle Swarm Optimization (PSO) algorithm [8] is used. It is suitable to deal with nonlinear multi-parameter problems. Being tested with synthetic and real data, the proposed approach has been proved to be an effective tool for solving such nonlinear inverse problems.

2. METHODOLOGY

2.1. Integrated approach

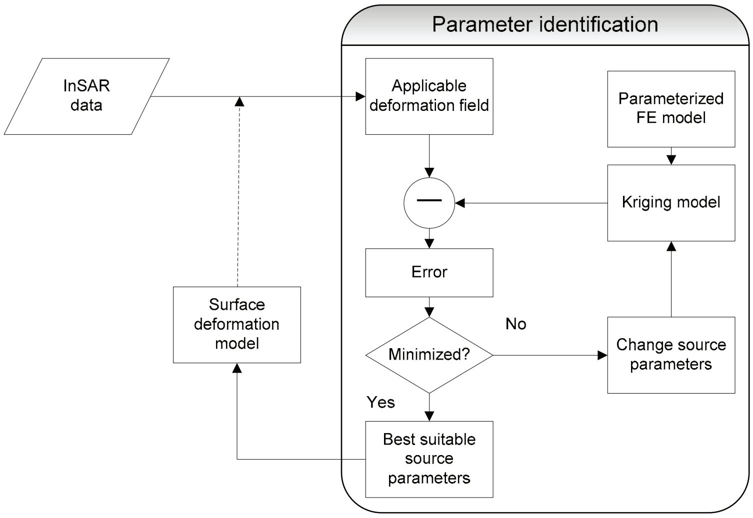

Fig. 1. Flow chart of the approach

In order to better understand the deformation pattern and the mechanic behavior of the earth movement beneath, a parameterized FE model is established. The settings of the FE model and the selection of parameters are based on prior geophysical and geological knowledge gained from literature surveys or in-situ measurements (if available). For identifying the suitable values of parameters, we created a Kriging model as the approximation of the original complex FE model. First, we applied space-filling Latin hypercube design (LHD) [9] on the parameter space to obtain the sampling points (parameter combinations), and then ran the FE model to get the corresponding output data for each sampling point. With the data pair, the Kriging model is trained. Then we used the well-trained Kriging model instead of the original FE model in the optimization procedure. After we determined the best suitable parameters, a surface deformation model can be generated by the FE model. It can provide a good hint for people to get a rough idea of what the deformation field would look like. It can be used as a reference during InSAR data processing and integrated in the estimation chain to get a more accurate estimation. When performing the same procedure at several time steps, we can obtain temporal evolutions for each parameter. Based on this, we can predict the deformation for the next time step. Since the FE model can well represent the complex mechanism by which the deformation occurs, it is capable to predict the deformation that varies nonlinearly with respect to time, which is much better than just extrapolating deformations.

2.2. Finite Element modeling

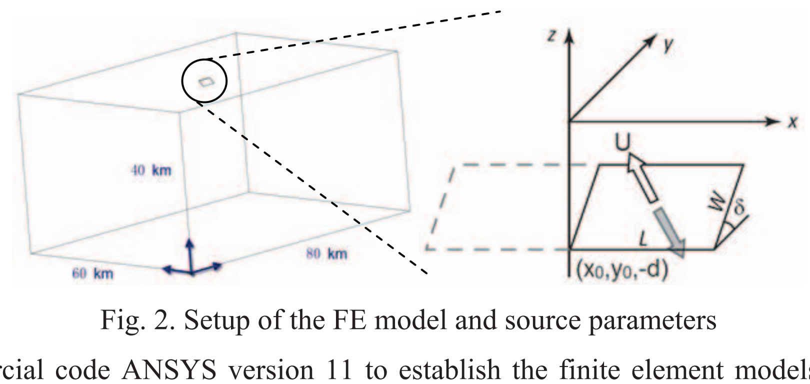

Fig. 2. Setup of the FE model and source parameters

We use the commercial code ANSYS version 11 to establish the finite element models. We consider a 3D cubic geometry with 80 km long, 60 km wide and 40 km deep. The area we are interested in is a 5x5 km^2 square in the middle of the surface. To gain accurate result of surface deformation, a finer mesh is used. A rectangular tension crack at a certain depth is modeled as the magma-filled dyke. We assume an opening perpendicular to the crack plane as the loading case. The chosen source parameters are showed in Fig. 2, which are the opening U, width of crack W, length of crack L, dipping angle δ and coordinates of the bottom center of the crack (x_0,y_0,-d). As boundary conditions, we assume zero normal displacement for all the side and bottom faces of the model. The numerical solutions are validated by comparing with results calculated by the Okada model. Of course, the FE model can be improved to be more realistic by including inelastic materials, heterogeneity and topography information gained from geological survey and other data sources. As the first step, we apply the simple settings to show the performance and potentials of the approach.

3. RESULTS

2.1. Interferometric results

SAR interferometry was recognized as a powerful technique to monitor surface deformation with mm-accuracy. Its all-weather, large-scale imaging capability makes it particularly useful for studying a variety of volcanic processes by analyzing surface deformation models, primarily before eruption occurs. For deformation mapping needs at least 2 SAR images are necessary that have been acquired at different times (repeat pass) and an extra DEM (digital elevation model) to eliminate the topographic phase. Because of the atmospheric turbulences, orbit errors and rest noise the accuracy of the single interferomtric measurement is hard to archive mm range. The time series technique is applied using long-time coherent scatters (PS-InSAR) from interferograms with common master to acquire long-term subsidence/uplift, where the affection of atmospheric delay and other errors (DEM, orbit, noise etc.) could be reduced directly using the information from time series or auxiliary information. 4 stacks of High Resolution Spotlight TerraSAR-X data with 1x1 m^2 pixel resolution were acquired from different looking-angles and cross directions and were collected for Exupery project [10]. The deformation estimated with PS-InSAR methods using DLR-Genesis software.

2.2. Results of identification process (Stromboli example)

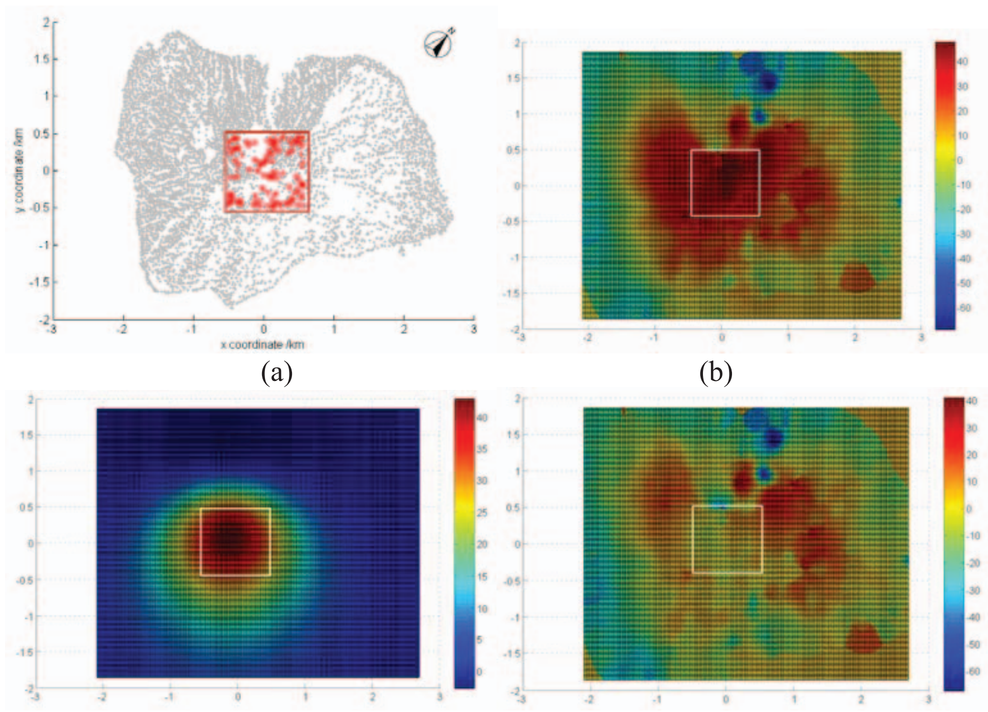

Fig. 3. (a) The investigation area (in the rectangle) and used points of PS-InSAR data (indicated by circles).
(b), (c) Vertical surface displacement of PS-InSAR data and FE model (mm/year).
(d) Residual vertical surface displacement

U (cm)	W (km)	L (km)	d (km)	x_0 (km)	y_0 (km)	δ (Degree)
38.219	0.7718	0.4737	1.5649	-0.1491	0.2518	50.01

Table 1. Identified results of source parameters

Based on the geological survey [11], a sub-region around the crater of Stromboli is selected. Only the surface deformation data of this sub-region is used in the identification procedure. The identified source parameters (Table 1) indicate the position and shape of the possible dislocation which causes the surface deformation. The surface deformation (Fig. 3c) generated by FE model with the best suitable source parameters is compared with the PS-InSAR data (Fig. 3b), and the residual is showed in Fig. 3d. They fit relatively well within the investigation area. Since the setup of FE model is much simplified, considering more realistic conditions such as topographical effect, inelastic material laws, multiple sources, etc. will improve the results and make the deformation prediction to be more reliable. Furthermore, since the metamodel is an approximation of the FE model, adjusting its parameters to obtain better performance will also improve the results.

4. CONCLUSION

This paper has proposed an integrated method for the nonlinear parameter identification problem by combining metamodel technique together with FE modeling. It has been applied to determine the proper parameters of magma-filled dykes according to the ground deformation data measured by InSAR measurements. To ensure the performance of the approach, it has been tested with large set of data generated by the Okada model. The approach has been applied to the real case of Stromboli volcano in Italy. The results show very good agreement between model and real deformations at solving such nonlinear inverse problems. Generally, FE modeling allows to consider more realistic models to describe the problem and conveniently to simulate the related mechanical behavior; while with the help of metamodels, the efficiency of the whole procedure is greatly improved. Both strengths are essential for real-time applications. The approach can be used to investigate the spatial-temporal evolution of source parameters and to predict surface deformations in the future. The approach can gain relatively good results with reasonable degree of accuracy. However it also indicates that due to the dependence and non-uniqueness of the parameters, the sole use of one kind of data is not sufficient to precisely determine all responses. The more types of geophysical data are involved, the better the results will be.

5. REFERENCES

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