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The contribution of Artificial Adaptive System to limit the influence of systematic errors in the definition of the kinematic behavior of an extremely-slow landslide

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ABSTRACT

This paper describes the application of some new mathematical algorithms, developed at Semeion Research Center and based on Artificial Adaptive System (AAS), to the redundant measurements of displacement of an extremely-slow landslide that may be affected by some systematic errors. The main aim is to understand if AAS may overcome their influence in the definition of the landslide kinematic behavior thus being able to use the measurements even though they differ by systematic errors. This would be a particularly good result for the monitoring of extremely-slow landslides that move at displacement rates less than 16 mm/year and can be recognized only with instrumentation, usually of geodetic type for the ground surface and inclinometers for the subsurface. In the short time, displacements are so small that they may include systematic errors of the same order of magnitude that can neither be identified nor reduced. For the monitoring of extremely-slow landslides it is therefore recommended to use redundant measurement systems and check the reliability of data by comparing the displacements. This paper shows how the use of the Artificial Adaptive System may get the information on the landslide kinematic even when there is no agreement between displacements measured with the different techniques. The validation of these results was made by comparing them with the well-known data field and a good agreement was found.

1. Introduction

The measurement of surface and subsurface displacements is requested for the geotechnical characterization of slope movements represented as a 3-D matrix (Leroueil, 2001), the three axis being the type of movement, the movement stage and the type of material. The spatial distribution of displacements helps to describe the type of movement, while the history of the rate of displacements may suggest the movement stage by relating the velocity to the triggering or aggravating factors. Spatial and temporal distributions of displacements define the kinematical behavior of a landslide. When dealing with extremely slow landslides that, accordingly to the velocity scale given by the International Geotechnical Society's UNESCO Working Party on World Landslide Inventory (WP/WLI) (1995) and by Cruden and Varnes (1996), move with rates less than 16 mm/year the displacements are detectable only with instrumentation because the revealing factors that would provide evidence of movement are not easily recognizable. Some examples of displacement monitoring of extremely-slow to slow landslides are given in Simeoni and Mongiovì (2007); Macfarlane (2009); Di Maio et al. (2010); Tombolato et al., 2011; Puzrin and Schmid (2012); Bovenga et al. (2013); Massey et al. (2013); Cohen-Waeber and Sitar (2013); and Miao et al. (2014).

The difficulties in monitoring extremely-slow landslides reside in the fact that the accuracy of measurements is not good enough to reduce the effects of the systematic errors (Simeoni and Ferro, 2015). It is reasonable and easy to understand that the systematic errors, which may affect the measures, might cause a different interpretation of the landslide kinematical behavior with respect to the real situation. Therefore, to reduce this risk, it is necessary to evaluate the reliability of the measurements using redundant monitoring systems (Dominici et al., 1995) (Dominici et al., 2014).

The different and redundant measurement techniques of geodetic type widely used for the ground surface movements of extremely-slow landslides are Total Station, GNSS and Levelling (Radicioni et al., 2012). Recently, remote sensing techniques such as ground-based or *space borne* (Corominas, 2014; Cohen-Waeber and Sitar, 2013; Cascini

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et al., 2010) InSAR have also been used. Subsoil movements are generally measured by means of inclinometers. It is well known that the inclinometer can (and do) introduce systematic errors (Mikkelsen, 2003).

Due to the complexity of the soil behavior, especially in problems involving great volumes and heterogeneous soils, since the early 1990s Artificial Intelligence has revealed to be a tool complementary to conventional computing methods to support decisions and assist in solving engineering problems (Toll, 1996). Artificial Neural Networks are Learning System models within the field of the Artificial Adaptive Systems and represent the most used applications in geotechnical engineering especially when the prediction of the soil behavior is requested (Shahin et al., 2009; Vijith et al., 2014; Sousa et al., 2014; Park et al., 2013).

This work investigates the contribution of the Artificial Adaptive System to a better understanding of the kinematic of extremely-slow landslides including displacement measurements that are affected by systematic errors. In order to verify this, one case study of extremely-slow landslide, named T64 and located in the alpine Isarco Valley in Northern Italy (Simeoni et al., 2014a, 2014b), was analyzed. This case had redundant information from Total Station and inclinometers with Total Station and inclinometer displacements similar in direction but greatly different in magnitude (Dominici et al., 2014).

These differences have a high probability of being correct due to different systematic errors which affect the measurements and which, at the same time, are really difficult to identify or reduce through classical measurement analysis. In the T64 case study, in fact, both inclinometer and Total Station measurements may achieve sub-millimeter precisions (Simeoni and Mongiovì, 2007) (Simeoni and Benciolini, 2007). Nevertheless as discussed in a previous research (Dominici et al., 2014), systematic errors due to the precarious stability of the geodetic reference system were identified to be of the order of millimeters. With some measurement analysis, a more reliable reference system was identified for T64, with the origin on vertex B3 and X axis oriented toward the point B1 (see Fig. 5) but it should still conserve some movements that introduce systematic errors in the vector of displacements. Also for inclinometers some problems with the installation or the measurement accuracy may occur (Mikkelsen, 2003; Simeoni, 2006) introducing systematic errors that cannot be easily reduced (Simeoni and Ferro, in press).

In the following paragraphs, some recent theories developed at Semeion Research Center are presented and applied to our case study focusing our attention on the added information which is obtainable using these algorithms on measurement analysis with respect to the classical approach. The results obtained are compared and validated with the geological model of the landslide and the characteristics of the sliding surfaces and boundaries.

2. Introduction to the Artificial Adaptive System

The Artificial Adaptive System (AAS) forms part of the vast world of Artificial Intelligence (AI), nowadays called more properly Artificial Sciences (AS). Artificial Sciences mean those sciences for which an understanding of natural and/or cultural process is achieved by the recreation of those processes through automatic models. In particular, Natural Computation would construct automatic models of complex processes and it represents an alternative to Classic Computation (CC). CC, in fact, has great difficult in modeling natural processes, especially since it often has to impose external rules to understand and reproduce them, when formalizing these processes in a mathematical model. Artificial Adaptive Systems are theories able to create artificial models simulating natural phenomenon. Artificial Adaptive Systems include Evolutive Systems and Learning Systems. Artificial Neural Networks are the most well-known Learning System models within AAS (Buscema and Grossi, 2009) (Buscema, 2011). We direct the reader to the bibliography for an exhaustive treatment of these systems. Some good examples of the application of Artificial Neural Network for the slope stability evaluation and the landslide displacements prediction are described in Wang et al. (2005) and Lian et al. (2015) respectively. Here, attention will be focused only on the algorithms that were applied to the active and extremely-slow landslide, seen as a natural phenomenon of diffusion. Diffusion may be synthetically described as the phenomenon of spatiotemporal propagation of a certain variable across a medium, where the modes of propagation crucially depend on the characteristic of the medium and the entities of interest (Buscema et al., 2013). Applying this concept to the physical phenomena of active and extremely-slow landslide, the variables are represented by the displacements over time of a certain number of monitored points while the medium is represented by the landslide body itself. As we mentioned in Introduction, the variable represented by the redundant measurement of displacements may be affected by different systematic error, and our approach uses some recently theories and algorithms developed at Semeion Research Center called respectively, Twisting Theory (TWT) and Crowd Clustering Algorithm (CCA) to get information on the landslide kinematic without rejecting any measurements.

2.1. Twisting Theory (TWT) and Twisting Algorithm (TWA)

Twisting Theory (TWT) and Twisting Algorithm (TWA) were developed by M. Buscema in 2010 at Semeion Research Center of Sciences of Communication in Rome (Buscema et al., 2013). TWT and TWA[1] are protected by a USA patent.

The main concept based on of Twisting Theory is to consider *M entities* located in the two-dimensional space, identified by their Cartesian Coordinates (x, y) or geographical coordinates (Φ, ω) observed at a sequence of times $n = 1,\ldots,N$ (see Table 1) which tend to move because of the action of some inherent forces. Each entity thus describes one pattern of movement, for simplicity is assumed to be linear, in the space and suppose moreover that the space is covered by a grid, and that the force that acts on the entities also acts on the grid, so that the change of position of the entities brings about accordingly a distortion of the original grid. We call all points belonging to the grid *geometrical points*.

The Twisting Theory (for short TWT) is a model able to infer how each geometrical point of the grid will modify its coordinates at each temporal step when any entity of the grid will move toward its new position (Buscema et al., 2013). To illustrate the idea, consider the following 36 × 36 grid with five entities and a trajectory in two time steps (see Fig. 1). The approach of TWT is to divide trajectories into N given sub-steps of equal length (Fig. 2), so that each entity is dynamically identified by the coordinates of its place of origin, by the moving local target corresponding to the movement at each single sub-step, and by the trajectory of the deformation.

TWT focuses upon the distances between a given geometrical point and the position of each given entity as it moves along its trajectory, measuring how distances vary at each sub-step of the trajectory, and is expressed in Eqs. (1) and (2).

$$d_{ij}^{S}(n) = \sqrt{\left(x_i^P(n) - x_j^S\right)^2 + \left(y_i^P(n) - y_j^S\right)^2} \tag{1}$$

$$d_{ij}^{T}(n) = \sqrt{\left(x_i^P(n) - x_j^T(n)\right)^2 + \left(y_i^P(n) - y_j^T(n)\right)^2} \tag{2}$$

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[1] M Buscema, Twisting Theory (TWT): a new theory and a new class of Algorithms able to model the global deformations of the space, considering the trajectories of only a little sample of points along the time flow. Applicant: Semeion Research Center & CSI. Inventor: M Buscema. USA Patent: 12/969,887. Deposited 16-Dec.-2010. Publication date: Mar. 4, 2014. Number: US8666707 B2.

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