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GPS- GIS and neural networks for monitoring control, cataloging the prediction and prevention in tectonically active areas

Vincenzo Barrile[a]*, Giuseppe M. Meduri[a], Giuliana Bilotta[b], Ugo Monardi Trungadi[a]

[a]*DICEAM - Faculty of Engineering "Mediterranea" University of Reggio Calabria,Via Graziella Feo di Vito 89100 Reggio Calabria, Italy*
[b]*Ph.D. NT&ITA, Dept. of Planning, University IUAV of Venice, Santa Croce 191, Tolentini 30135 Venice, Italy*

Abstract

Monitoring the system of active faults in Castrovillari, carried out in time by the Geomatics of the University Mediterranean of Reggio Calabria, through GPS measurement onsite on test networks, created a database of crustal movements, useful for different studies and analysis of tectonic and deformation type. With the help of the powerful spatial and temporal data processing tools offered by GIS, and integration with traditional artificial intelligence models of neural networks, we created a platform that can not only to handle the huge amount of data processing, analysis and visualization tools, but also can get the first results for predicting displacements/distortions also useful for civil protection.

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Keywords: GPS; GIS; Fuzzy logic; Deformations; Earthquakes; Reggio Calabria

1. Introduction

This research is the implementation of a GIS platform which allows not only managing and cataloging, but also comparison of the extent of movements, having GPS data related to measurement campaigns in the area of Castrovillari, test networks for monitoring, and control on active faults, initially established and detected by the Polytechnic of Milano. Also, thanks to the development of neural network forecasting, powerful IT tool, by means

* Corresponding author. Tel./fax: +39 0965 1692301.
E-mail address: vincenzo.barrile@unirc.it

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mathematical models that for their characteristic of self-learning can be used to solve problems of artificial intelligence in fields where there is no appropriate analytical model, we experienced only on a limited set of navigation data audit networks active faults in the period 1996-2015: a spatial-temporal pattern of detected movements that can also allow to make a prediction of the extent of movements. This prevision could be helpful in the planning of campaigns, so as to carry them out if there are any conditions to suggest significant deformation events in areas of study (Barrile & Crespi, 1995), (Barrile, Meduri, & Bilotta, 2014).

In this way we could therefore limit costs, because the campaigns would be carried out only when it would presumably be convenient their implementation and in the presence of significant values. The same methodology was applied for the prevention of disasters such as seismic ones where the area is characterized.

The platform can be exported to all the metropolitan area in order to control and prevent, when it is decided to establish GPS networks and repeat over time in an area of strong seismic risk as the metropolitan area of the Strait.

2. GIS platform

The proposed GIS platform allows to determine the meaningfulness, (through the fulfillment of appropriate statistical tests) of the movement on GPS network test repeated in the time (Barbarella, Crespi, & Fiani, 1995). They have common point without a priori information on the stability of the network point coordinates . In detail, assigned a series of GPS data repeated in the time, through the GIS potentiality it possible to have:

- a free adjustment of the single networks;
- the Geodetic Datum's choice (set of the network points statistically stable) through statistical test;
- the estimate of the new coordinates of the network points on identified Datum (transformation);
- a constrained networks adjustment, singularly in the identified Datum;
- calculating displacements of the network points.

Shown below a set of GIS' screen realization, illustrating the application of the methodology to the area in exam.

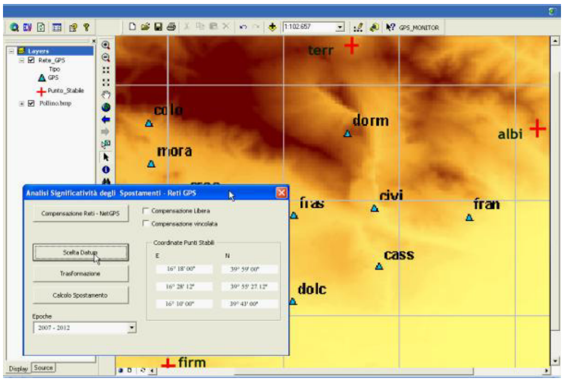

Fig 1. free adjustment network and choice datum

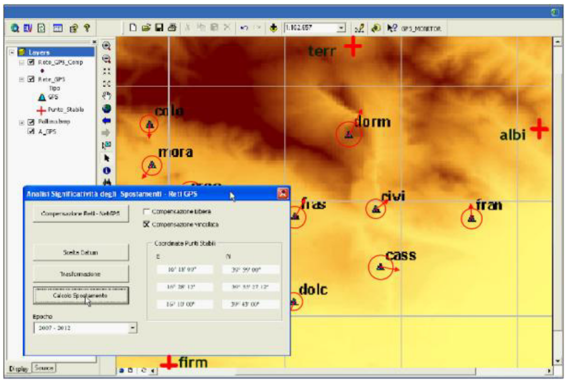

Fig 2. transformation and calculus movement with a secure adjustment in the Datum

3. Fuzzy logic

The Fuzzy logic allows to convert basics of human experience in numerical algorithm, with the advantage to obtain automatically procedure able to simulate an artificial experience.

A fuzzy set is defined by a characteristic function that associates, to every element of universal-set, a function or a membership value expressed as a real number in the interval [0,1]. Therefore a fuzzy set can be considered as an abstract quantity, nearest in a certain amount to others. To understand how works a fuzzy set, we can start from a fixed and universal X set and, on it, to define a fuzzy set F(X). In this we can quantify the similarity of two fuzzy set A e B, in F(X) about a S function, called similarity, that defines and satisfies the following property:

1) S (A, B) = S (B, A) → the states that judges the similarity are symmetric (A is similar to B and B is similar to A at the same level);

2) If $A \subset B \subset C$ then S (A, B) ≥ S (A, C) and S (B, C) ≥ S (A, C) with A, B, C in F (x) → the dimension of similarity is monotonic;

3) S (D, D) = max $_{A, B\, \epsilon\, F(x)}$ S (A, B), with D ϵ F (x) → the states are pensive; this propriety stabilize that the degree of similarity of any sets is more tall;

4) S (C, C) = 0, $\forall$ C $\in$ P (x) with P (x) belong to all fuzzy sets → the states of similarity between a set ad an other are it zero.

The fuzzy similarity can be express in different ways:

$$S_1(A, B) = \frac{1}{n}\sum_{i=1}^{n}\frac{min(\mu_A - \mu_B)}{max(\mu_A - \mu_B)} \qquad S_2(A, B) = \frac{\sum_{i=1}^{n}\left\|\mu_A - \mu_B\right\|}{n} \tag{1}$$

$$S_3(A.\ B) = 1 - \sum_{i=1}^{n}\frac{\left\|\mu_A - \mu_B\right\|}{\mu_A - \mu_B} \qquad S_4(A, B) = \frac{1}{1 + \left\|\mu_A - \mu_B\right\|} \tag{2}$$

Where *n* is the number of the elements contained in fuzzy set A e B, and $\mu_A = \mu_A(x_i)$ e $\mu_B = \mu_B(x_i)$ are the values of membership of the fuzzy sets' elements A e B, respectively.

With the availability of GPS measurements in the area of Castrovillari was tested a methodology to assess the effectiveness of the use of these fuzzy techniques and similarity, in anticipation of shifts in Cassano allo Ionio.

Compared to a benchmark year (in 1996) we can compare movement data of the next years through particular formulations of fuzzy similarity indicating to what extent a year approaches or moves away (in terms of trips) to the base year and building therefore a trend of similarity.

This trend is reproducible by means of polynomial functions that can be built with the usual elementary numerical techniques. The resulting function allows to translate the problem of trends search of trends in equivalent predictive problem where the function y = f (x) (x = year and y = similarity related to year x) built polynomially makes deterministic the problem of the prediction. In this way we can determine the similarity for the year of interest (in 2015), and obtain the displacement, or for reversal of the similarity function or through graphical comparison and/or similarity tables.

In summary, having available data of Cassano allo Ionio between 1996 and the 2015, was determined in advance the trend of similarity between 1996 and 2010; This trend resulted in a polynomial function allows to predict the value of similarities and therefore moving allegedly in year 2012 to compare with the value of actual displacement (as available) of 2015 in order to evaluate the effectiveness of the experiment carried out. The procedure for calculating displacements prediction foresaw the construction of matrices of correlations between similarities in the years 1996-2010 in order to determine a trend of similarities from which derive the displacement planned for 2015. Monthly arrays constructed by correlating the similarity values for each month of each year compared to the same month last year and the annual matrix containing similarity values among various years were supplemented with the values of similarity achieved by implementing this in Matlab:

$$S(A, B) = \frac{1}{1 + \left\|\mu_A - \mu_B\right\|} \tag{3}$$

where μ_A is the average of the values of xi of year it (1997-2010) and μ B is the average of the values of x the reference year 1996. Similarity matrices are given only as an example (Fig. 4 and Fig. 5) and the calculated values for the generic month and general annual.

Jan S(97-96)													
Jan S(98-96)	Jan S(97-96)												
Jan S(99-96)	Jan S(98-96)	Jan S(97-96)											
Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)										
Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)									
Jan S(02-96)	Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)								
Jan S(03-96)	Jan S(02-96)	Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)							
Jan S(04-96)	Jan S(03-96)	Jan S(02-96)	Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)						
Jan S(05-96)	Jan S(04-96)	Jan S(03-96)	Jan S(02-96)	Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)					
Jan S(06-96)	Jan S(05-96)	Jan S(04-96)	Jan S(03-96)	Jan S(02-96)	Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)				
Jan S(07-96)	Jan S(06-96)	Jan S(05-96)	Jan S(04-96)	Jan S(03-96)	Jan S(02-96)	Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)			
Jan S(08-96)	Jan S(07-96)	Jan S(06-96)	Jan S(05-96)	Jan S(04-96)	Jan S(03-96)	Jan S(02-96)	Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)		
Jan S(09-96)	Jan S(08-96)	Jan S(07-96)	Jan S(06-96)	Jan S(05-96)	Jan S(04-96)	Jan S(03-96)	Jan S(02-96)	Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)	
Jan S(10-96)	Jan S(09-96)	Jan S(08-96)	Jan S(07-96)	Jan S(06-96)	Jan S(05-96)	Jan S(04-96)	Jan S(03-96)	Jan S(02-96)	Jan S(01-96)	Jan S(00-96)	Jan S(99-96)	Jan S(98-96)	Jan S(97-96)

Fig 4: similarity matrix scheme monthly (January)

S(97-96)													
S(98-96)	S(97-96)												
S(99-96)	S(98-96)	S(97-96)											
S(00-96)	S(99-96)	S(98-96)	S(97-96)										
S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)									
S(02-96)	S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)								
S(03-96)	S(02-96)	S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)							
S(04-96)	S(03-96)	S(02-96)	S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)						
S(05-96)	S(04-96)	S(03-96)	S(02-96)	S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)					
S(06-96)	S(05-96)	S(04-96)	S(03-96)	S(02-96)	S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)				
S(07-96)	S(06-96)	S(05-96)	S(04-96)	S(03-96)	S(02-96)	S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)			
S(08-96)	S(07-96)	S(06-96)	S(05-96)	S(04-96)	S(03-96)	S(02-96)	S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)		
S(09-96)	S(08-96)	S(07-96)	S(06-96)	S(05-96)	S(04-96)	S(03-96)	S(02-96)	S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)	
S(10-96)	S(09-96)	S(08-96)	S(07-96)	S(06-96)	S(05-96)	S(04-96)	S(03-96)	S(02-96)	S(01-96)	S(00-96)	S(99-96)	S(98-96)	S(97-96)

Fig 5: annual similarity matrix scheme

Table1. values A, B and similarities monthly (January)

Period	$\mu_A(x_i)$	$\mu_B(x_{96})$	S
Jan 97 - Jan 96	4,9833	4,9832	0,6198
Jan 98 - Jan 96	4,9832	4,9832	0,6171
Jan 99 - Jan 96	4,9832	4,9832	0,6175
Jan 00 - Jan 96	4,9832	4,9832	0,6227
Jan 01 - Jan 96	4,9833	4,9832	0,6228
Jan 02- Jan 96	4,9833	4,9832	0,6227
Jan 03 - Jan 96	4,9832	4,9832	0,6227
Jan 04 - Jan 96	4,9831	4,9832	0,6342
Jan 05 - Jan 96	4,9831	4,9832	0,6377
Jan 06 - Jan 96	4,9830	4,9832	0,6642
Jan 07 - Jan 96	4,9832	4,9832	0,6677
Jan 08 - Jan 96	4,9832	4,9832	0,6442
Jan 09 - Jan 96	4,9520	4,9832	0,4983
Jan 10 - Jan 96	4,9312	4,9832	0,8081

Similarly has implemented a procedure for correlation between the similarities of each year compared to the base year. In this way with a neural network training procedure and with the aid of fuzzy similarity we can translate a stochastic problem in equivalent deterministic and get a trend of similarity whose mathematical formulation is given by $y = 0.006x^2 – 0.046x + 0.622$; we can project and calculate the value of moving average for 2015 to compare with the real value.

Table2. Values A, B and annual similarity

Period	$\mu_A(x_i)$	$\mu_B(x_{96})$	S
Annual 1997-1996	4,9860	4,9877	0,6165
Annual 1998-1996	4,9860	4,9877	0,6111
Annual 1999-1996	4,9863	4,9877	0,6184
Annual 2000-1996	4,9863	4,9877	0,6195
Annual 2001-1996	4,9865	4,9877	0,6295
Annual 2002-1996	4,9865	4,9877	0,6297
Annual 2003-1996	4,9868	4,9877	0,6295
Annual 2004-1996	4,9867	4,9877	0,6296
Annual 2005-1996	4,9869	4,9877	0,6325
Annual 2006-1996	4,9869	4,9877	0,6596
Annual 2007-1996	4,9873	4,9877	0,6725
Annual 2008-1996	4,9791	4,9877	0,6443
Annual 2009-1996	4,9451	4,9877	0,4984
Annual 2010-1996	4,9209	4,9877	0,8083

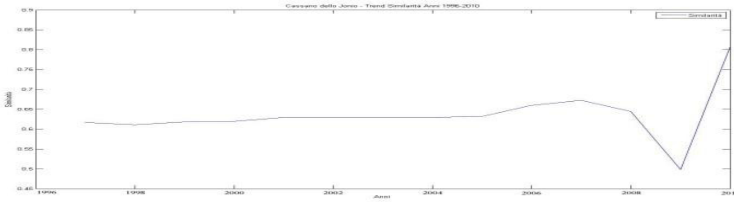

Fig 6: Similarity of trend chart x-Cassano allo Ionio year 1996-2010

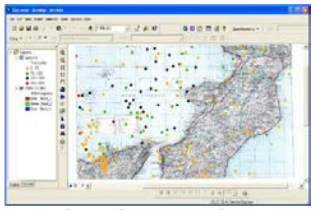

Fig 7: Evolution by Magnitude

Using the same methodology, we wanted to also experience a possible use of the potential of neural networks for possible crustal strain rate anomalies preceding an earthquake of certain intensity, in case you're given a clear link between the event and the deformation or strain rates (Barzaghi, 2002). We cannot predict earthquakes because no study failed to demonstrate a clear cause and effect relationship. However for different events, surveys and research have shown how the approach of an earthquake was observed significant variations of some useful parameters to possible interpretations. In the literature there are several examples that refer to the presence of chemical elements (sodium and hydrogen) in abnormal amounts within the water sources or increase of crustal deformation phenomena, as well as underground radon. In that regard, having available the database of GPS observations of the monitoring network of Castrovillari, and considering the same area of Cassano allo Ionio were questioned databases of significant earthquakes in the reporting period and within a radius of 5 km around the monitoring station, cataloging them for magnitude. Particularly in the period 1996 – 2015 queries provided two events with magnitude $1.5 \leq M$ 3 (Table3), 11 events with magnitude $3 \leq M \leq 4.5$ (Table 4) while no event with M 4.5. Notice in this regard as well as in this case, the queries were performed on a GIS previously built for the cataloguing of earthquakes throughout the metropolitan area of the Strait highlighting, the evolution of seismic measurements over time, with depth and ranking the earthquakes as a function of magnitude) for query requests.

Table 3. Earthquakes with magnitude $3 \leq M \leq 4.5$

Data from: 1996/01/01 to: 2015/12/31 Total Earthquakes: 2 Area Latitude: 39.78043 Longitude: 16.32114 Distance (km): 5.0 Magnitude Min: 3.0 Max: 4.5				
Origin Time (UTC)	Latitude	Longitude	Depth	Magnitude
2008-01-15 02:38:31.250	39.812	16.331	16.05	3.00
1997-08-17 02:35:10.440	39.812	16.289	5.00	3.00

Were related, through the point-in-time, tables of GPS observations to those of seismic events by analyzing the trend of deformation before and after them. Only in one case we had the presence of a phenomenon most noticeable deformation in the months leading up to the event. It was therefore trained neural network using fuzzy similarity formulations details indicating "to what extent changes in strains are approaching or receding, with a fixed tolerance range, the reference speed" and therefore building a trend of similarity. When experiencing the same conditions of deformation and/or strain rates, we can alert on the possibility of an event of a given magnitude. However, none of the data we are in possession of a further year plays upon the conditions verified in the landmark event.

Table 4. Earthquakes with magnitude 1.5 ≤ M < 3

Data from: 1996/01/01 to: 2015/12/31 Total Earthquakes: 11 Area Latitude: 39.78043 Longitude: 16.32114 Distance (km): 5.0 Magnitude Min: 1.5 Max: 2.9

Origin Time (UTC)	Latitude	Longitude	Depth	Magnitude
2015-04-02 10:53:07.220	39.746	16.278	8.00	2.5
2014-03-22 05:38:32.140	39.803	16.265	9.07	1.8
2014-03-10 03:53:04.340	39.736	16.281	8.07	1.8
2012-08-17 09:37:43.680	39.738	16.329	6.05	1.8
2012-06-06 17:56:47.850	39.795	16.282	10.00	1.5
2010-07-07 09:02:58.390	39.785	16.303	7.07	1.6
2008-01-15 02:39:46.830	39.815	16.285	4.08	2.5
2000-12-25 00:57:18.260	39.784	16.275	8.02	2.7
2000-07-20 20:16:34.160	39.791	16.286	9.04	2.4
1996-10-04 07:39:47.870	39.815	16.287	10.00	2.4

4. Conclusions

The use of GIS (Barrile, Armocida, & Di Capua, 2009) and Neural Networks on GPS dataset repeated over time provided satisfactory and promising results regarding the prediction of displacements. Despite having used in this application one component of displacement, certainly will provide even more satisfactory results with the use of the three components of the displacement. Very interesting is also the approach inherent prediction of seismic events even though the experimentation is still at an early stage and if need availability of a wider database and determine functional links (if any) plus some between the parameters. The combined use of GPS GIS neural networks proposed in this application for the prediction of earthquakes is therefore a first approach. It can provide certainly encouraging results when the indicators that can lessen the degree of randomness of the events will be available. Particularly useful appear these methodologies to be applied throughout the metropolitan area of the Strait also civil protection purposes being the same metropolitan area, as noted, a seismically active area.

References

Barbarella, M., Crespi, M., & Fiani M. (1995). Analisi statistica della significatività degli spostamenti. *Atti del 13º Convegno del Gruppo Nazionale di Geofisica della Terra Solida*, Rome, 319-330.

Barrile, V., & Crespi, M. (1995). Compensazioni ed analisi di rilievi GPS per il controllo di deformazioni nell'area Etnea, *Atti del 14º Convegno del Gruppo Nazionale di Geofisica della Terra Solida*, Rome, Oct. 23-25, 309-318.

Barzaghi, R. (2002). Determinazione dello stile di deformazione e dello stato di sforzo dell’arco Calabro. *Framework Program 2000–2002, Annual Report – 1st Year Of Activity*.

Betti, B., Crespi, M., & Sguerso, D. (1994). Stabilità del sistema di riferimento nella determinazione di reti GPS. *Bollettino Sifet*, *4:* 67-88.

Parrillo, F., D’Amico, S., Cacciola, M., Morabito, F.C., Barrile, V., Versaci, M., & Caccamo, D. (2005b). Neural Networks Radial Basis Function and Method Delta/Sigma for the Forecast of Strong Replicas). *Atti del 24º Convegno del Gruppo Nazionale di Geofisica della Terra Solida*, Rome, Italy, 197–200.

Cinti, F.R., Moro, M., Pantosi, D., Cucci, L.A., & D’Addezio, G. (2002). New constraints on the seismic history of the Castrovillari fault in the Pollino Gap (Calabria, Southern Italy), *J. Seismol., 6*: 199-217.

Barrile, V., Meduri, G. M., & Bilotta, G. (2014). An open GIS for the significance analysis of displacements arising from GPS networks repeated over time: an application in the area of Castrovillari. WSEAS Transactions on Signal Processing, *10:* 582-591.

Barrile, V., & Bilotta, G. (2014). Self-Localization by Laser Scanner and GPS in automated surveys. *Computational Problems In Engineering. Lecture Notes In Electrical Engineering, 307*: 293-313.

Barrile, V., Meduri, G. M., & Bilotta, G. (2014). Monitoring and GPS controls, over time, of the active fault in Castrovillari. *Latest Trends In Energy, Environment Ad Development - Proceedings Of 7th International Conference On Environmental And Geological Science And Engineering (Eg '14)*, Salerno, Italy, June 3-5, *Energy, Environmental And Structural Engineering Series*, 169-175,

Barrile, V., Armocida, G., & Di Capua, F. (2009). Advanced Thematic Mapping: GIS/Neural Networks Application for tracking Isoseismic Lines. *Wseas Transactions on Environment and Development, 5*: 435-444.

Barrile, V., Armocida, G., & Di Capua, F. (2009). Urban Planning and Economic Revitalization of Historic Centers: A Mis-GIS Application. *Wseas Transactions on Environment and Development, 5*: 556-565.

D'Amico, S., Cacciola, M., Parrillo, F., Morabito, F. C., Versaci, M., & Barrile, V. (2009). Heuristic Advances In Identifying Aftershocks In Seismic Sequences. *Computers & Geosciences*, *35*: 245-254.

Laboratorio Geomatica Università “Mediterranea” degli Studi di Reggio Calabria, Banca Dati relativa alle Campagne di Misura GPS effettuate nell’area di Castrovillari, Campagne di misura 2007-2014 Http://Iside.Rm.Ingv.It/