T-MAP: an automatic approach for a GIS-ready landscape monitoring

Anna Nora, Tassetti[1], Eva Savina, Malinverni[1], Adriano, Mancini[2]

[1] DARDUS, Faculty of Engineering, Marche Polytechnic University, Via Brecce Bianche, 60131, Ancona, Italy
n.tassetti@univpm.it, e.s.malinverni@univpm.it

[2] DIIGA, Faculty of Engineering, Marche Polytechnic University, Via Brecce Bianche, 60131, Ancona, Italy
mancini@diiga.univpm.it

Abstract. SI^{2}G (Geographical Intelligent Information System) is a spin-off company of Marche Polytechnic University (Ancona, Italy), built up in 2008 by a cross-curricular team belonging to the Engineer faculty. GI-Thema project is developed by SI^{2}G as ICT service and solution provider ranging from Remote Sensing and landscape monitoring (in particular Land Cover/Land Use mapping) to up-to-date computer cartography, Web-GIS solutions and Geographic Information Systems.

The GI-Thema project goes into the landscape monitoring providing new automatic approaches, based on machine learning and image processing techniques and allowing to update geographic information in short time and high accuracy. According to this project, T-MAP software is developed inside the uDiG GIS environment and organized into an user friendly modular structure that allows to enhance and widen its performance in particular in terms of landscape classification (automated hybrid land cover mapping tool) and change detection analysis in general (i.e. automated road detection tool and network updating). Moreover, thanks to the uDiG environment, the GIS interoperability is achieved by the T-MAP software which is able to handle raster, shape and tabular data, facilitating the change detection analysis and its use as a valid GIS decision support system.

In particular, to fulfill automated land cover mapping, T-MAP combines the pixel-based and object-based approaches into a hybrid classification solution that makes use of a segmentation tool and a rule-based thematic categorization. The output is a thematic map (Land Cover/Land Use) characterized by a good performance and a custom-designed legend. T-MAP's strong point is also a detailed accuracy assessment by means of stability maps and ad-hoc indexes that help the user to recognize stable regions from the instable ones which should be verified before being used.

Lastly, as an example of change detection analysis, T-MAP road tracking tool is presented and it is shown its performance in presence of occlusion (e.g., shadows, cars, trees).

Keywords: Hybrid classification, Land Use/Land Cover, Stability map, Change Detection

1 Introduction

Land cover is a key environmental information and a must for understanding causes and trends of regional, social and economic development and global environmental changes. Consequently it results a fundamental variable for supporting a proper landscape management. Planning, policy formulations and decision making, to be realistic and sustainable require qualitative and quantitative information mainly on existing land uses. Therefore, Land Cover/Land Use (LCLU) maps are needful for several organizations such as governmental agencies and research institutions that have to deal with land monitoring and management decisions.
For example all the European countries, to answer several recent environmental, agricultural and landscape European Union's directives, should strengthen their structures and provide new tools devoted to landscape resources transformation monitoring according to different aspects (urban, agricultural, landslide/fire hazard etc.). Nowadays the need of a more updated land use/coverage database and landscape information in general, at proper scale of representation, represents an urgent issue.

Remote sensing combined with GIS tools potentially can give quick reply to these new needs providing timely information products in different geometric and thematic scales. Anyway the effort to manually photointerpret land use data is still very high in terms production time and costs and cannot keep up with the development pace.

In this context new procedures are taking off and new landscape analysis tools must be proposed with the aim of being more automatic, quick, low-cost, user-friendly and accurate as possible and in the same time of following detailed and well-structured standards such as the European Corine Land Cover (CLC) nomenclature.

The authors of this work form a cross-curricular team (computer and geomatic scientists) whose research steers towards ICT services and solutions, ranging from Remote Sensing and landscape monitoring (in particular LCLU) to up-to-date computer cartography, Web-GIS applications and Geographic Information Systems. This research led the team (in 2008) to the SI^{2}G spin-off company [5] incorporation, belonging to Marche Polytechnic University, with the mission of providing a cross-curricular know-how as response to new user needs and finding engineering and marketable problem solutions to the landscape analysis and monitoring.

The key product, here described and called T-MAP, is developed and marketed by SI^{2}G as GIS-ready and user friendly solution for thematic mapping (i.e. LCLU mapping) in contrast with the traditional expensive and time consuming photointerpretation process.

In particular T-MAP software includes innovative image processing tools (Fig. 1) that are particularly well-suited for land cover mapping applications with remotely-sensed data.

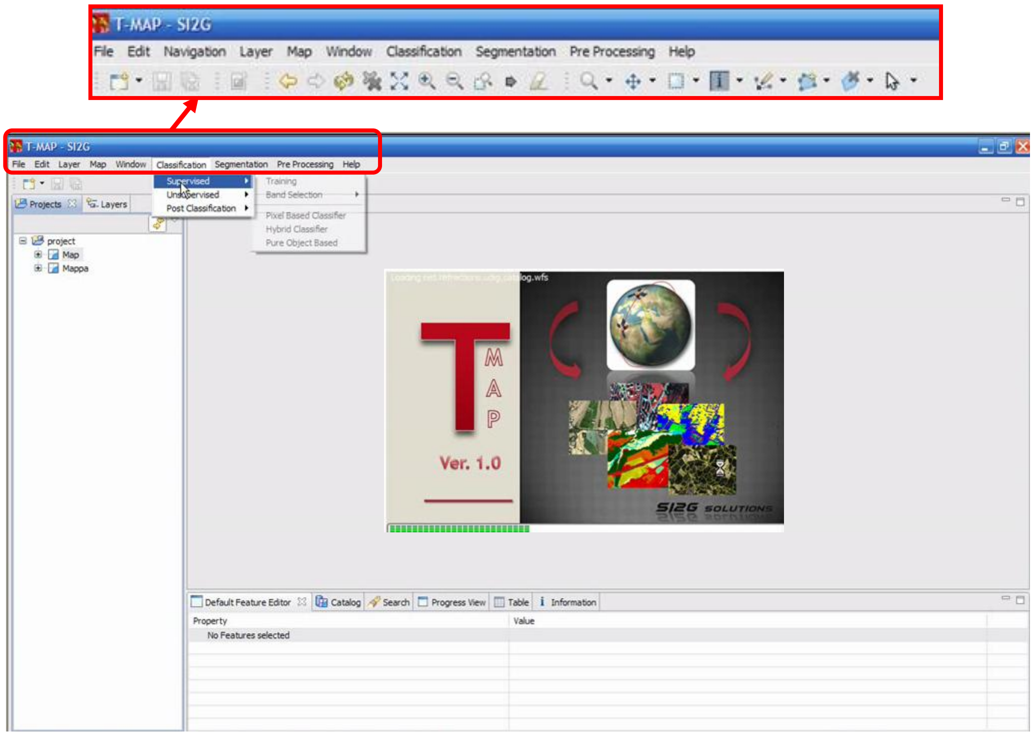


Fig. 1. T-MAP software and its main tools (Segmentation, Classification and Pre-processing tools)

T-MAP software is based on GeoTools library and LGPL licence and developed inside the GIS desktop uDIG [4]. In this way it lends itself to a broad application base since it provides a rich and powerful toolset in a flexible and modular organization, according to a wider GI-Thema project.

This also allows to fulfill GIS interoperability and widen T-MAP performance, facilitating its use as a valid GIS decision support system.

The paper is organized as follows. Section 2 introduces the proposed T-MAP tools and its main functionality while Section 3 gives an overview of its applications in terms of some land cover mapping and change detection results. Lastly, conclusions are drawn in Section 4.

2 T-MAP: tools and functionality

T-MAP's main innovative feature consists in its hybrid automatic classification solution that combines pixel and object/region-based approaches, making use of a segmentation tool (cf. Section 2.1) and rule-based segment classification (cf. Section 2.2). The segmentation creates an image of segments while the classifier categorizes each segment utilizing a customized Winner Takes All (WTA) approach. In this way it is possible to incorporate the advantages of supervised pixel-based approach (higher reliability and detail) as well as object–based segment classification (GIS-ready mapping product and customization chance in terms of scale and legend). This innovative feature makes T-MAP highly suited for applications that utilize medium to high resolution satellite imagery and useful for those mapping land cover and monitoring land change.
This section explores how this functionality is incorporated within T-MAP and also outlines the workflow.

2.1 Image segmentation

An accurate and precise segmentation is the prerequisite to extract a set of meaningful entities better representing objects in the landscape and in this way useful for each step of thematic mapping process, from defining training sites to classifying from these segments.
The segmentation module provided by T-MAP generates an image of segments where pixels identified within a segment share a homogeneous spectral similarity, going by some spatial parameters (i.e. compactness, convexity etc.).
In particular the tool is based on an image pyramidal approach that combines edge-detection with region-growing techniques and is driven, in its re-distribution step, by spectral and spatial parameters in order to outline the real objects localized into the image with small computation time and strong accuracy.

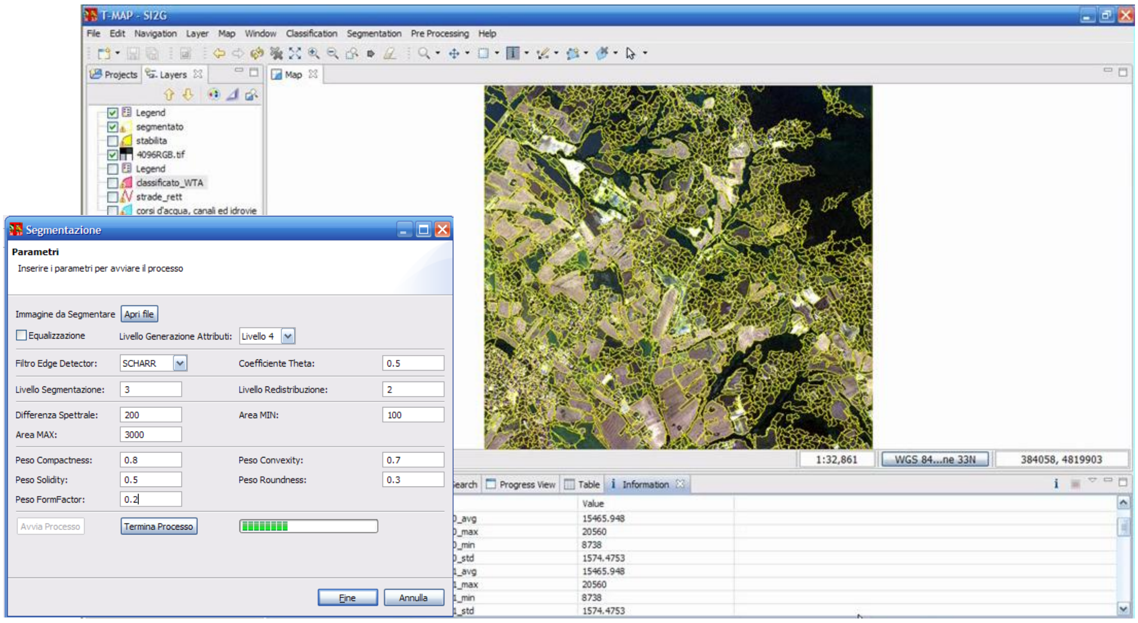


Fig. 2. T-MAP segmentation tool: segmentation dialog box (left) and a segmentation result (right)

Setting (Fig.2) some segmentation parameters (Minimum Mapping Unit, spectral difference, number of pyramid levels, scale factor etc.), it is possible to customize and drive the analysis in order to extract specific features of interest (buildings, roads, segments etc.).
In this way the proposed image segmentation tool comes in handy for specific change detection and landscape monitoring analysis.

2.2 Rule-based segment classification

The proposed T-MAP hybrid solution is presented below in Fig.3.

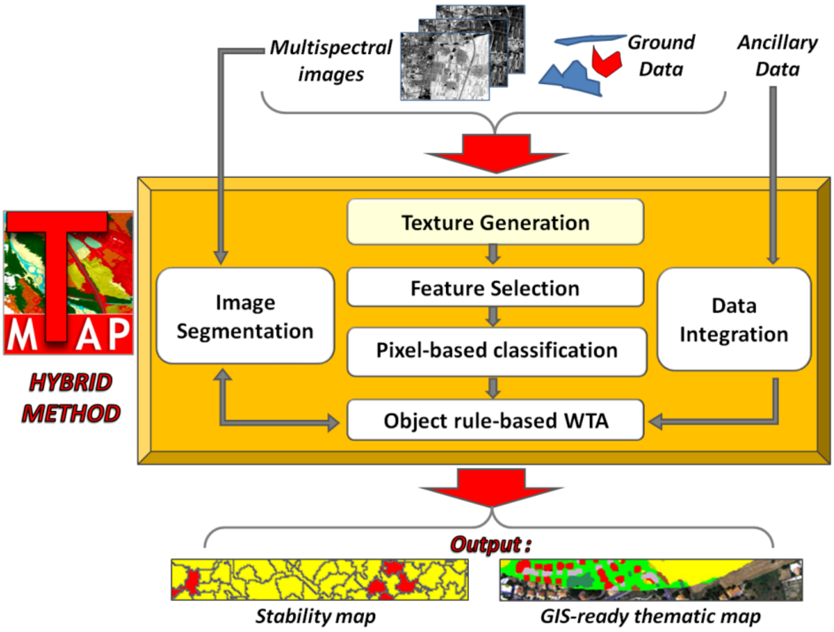


Fig. 3. Hybrid methodology

Before running the supervised classification, T-MAP gives the user a wide range of tools for the generation and the following supervised selection of textural (Gabor's, Law's and Haralick's texture) and other additional features (vegetation indexes and other band ratio) to augment the spectral bands and, in this way, better characterize specific land cover patterns (i.e. CLC class 2.2, "Permanent crops").
An object rule-based processing is then adopted to improve the pixel-based classification result (i.e. Adaboost classifier) in terms of spatial consistency, semantic representation and number of extracted classes.
In particular a customized Winner Takes All (WTA) approach augmented with rules is applied within each segment to determine its class assignment and turn it into a meaningful and realistic GIS-ready object.
This object-oriented approach enables spatial information (i.e. geometrical segment attributes and WTA derived spatial relationships such as membership class percentages) to drive, together with the spectral attributes, first the extraction of meaningful segmented regions and then their sorting into thematic land cover classes. Moreover it allows allow to achieve better accuracy, extract more land cover classes and go also over the simple spectral signature identification towards heterogeneous classes categorization(i.e. CLC class 2.4, "Heterogeneous agricultural areas").
The output is a thematic map (Land Cover/Land Use) characterized by a custom-designed legend and a good performance in terms of accuracy and legend detail.
T-MAP's strong point and additional output is also a detailed accuracy assessment by means of stability maps and ad-hoc indexes that help the user to recognize stable regions from the instable ones which should be verified before being used. In this way he/she can decide to charge a photo-interpreter to only verify the classification for these instable segments.

3 T-MAP: the applications

3.1 Land Cover/Land Use mapping

Experimental results carried out with multi-spectral high resolution ADS40 images show that the proposed T-MAP automated approach can provide reasonable classification results in comparison

with the conventional pixel-based classification methods. The approach allows also to reach higher accuracy, topological correctness, GIS-ready results and is able to extract more LCLU classes.
The produced GIS-ready thematic map (Fig.4) goes into the third CLC legend level and the accuracy can be improved through different stages.
The per-pixel classification accuracy is enhanced, first, involving textural analysis and additional features in the classification schema and then turning it into an object-oriented approach until to reach an overall accuracy of 89% and the extraction of 12 CLC classes with Producer', and User's accuracies bigger the 75%.
In particular the rule-based WTA approach allows to extract complex cultivation patterns (CLC class 2.4.2) and to distinguish between continuous and discontinuous urban fabric (respectively, CLC class 1.1.1 and CLC class 1.1.2).

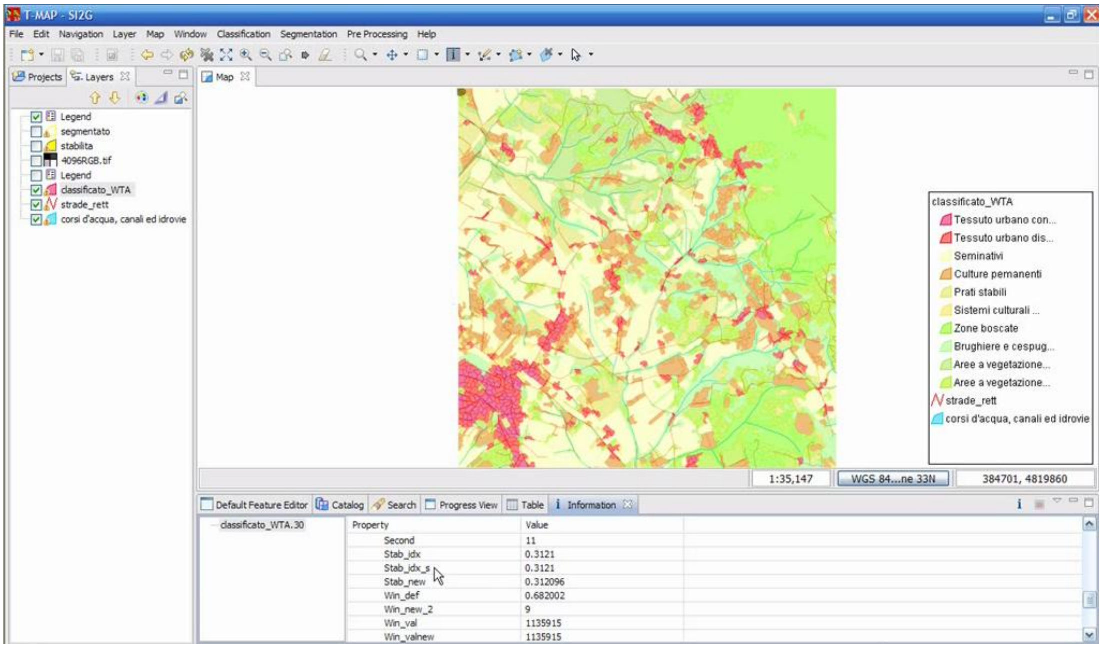


Fig. 4. T-MAP GUI and the GIS-ready thematic map

To know where correct and erroneously classified regions are really located in the whole dataset, the produced thematic map comes with its correlated stability map [2] that deepens the overall accuracy (coming from the confusion matrix results) in terms of Confusion Indexes (CI) related to the stability/reliability degree of each extracted and classified segment. The final stability map (Fig.5) can directly be derived thresholding the CI values and underlining instable polygons characterized by low winner's percentages.
The stability map becomes in this way a valid instruments that drives the user in the LCLU map consultation, showing which polygons are not correctly classified: they are to be refined into an upper CLC level class or photointerpreted or, at least, not to be taken into account at all.
The stability experimental results confirm the performance of the proposed hybrid approach with 86% of stable regions (in yellow, Fig.5) against 14% of unstable ones (in red, Fig.5) where the spectral signature is heterogeneous and additional analysis and/or rules must be defined.

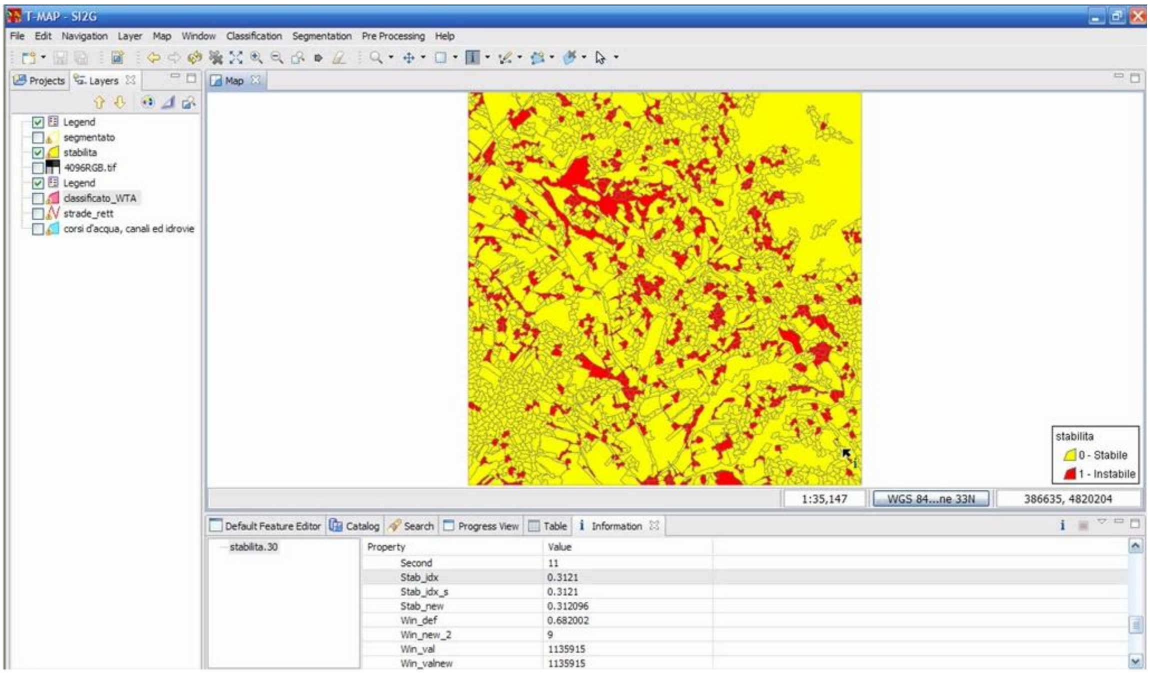


Fig. 5. T-MAP GUI and the stability map

3.2 Land Change Detection

Change detection in remotely sensed imagery is defined as the procedure of quantitatively analyzing and identifying changes occurred on the earth's surface from remotely sensed imageries acquired at different times. This geographic understanding of land use change is one of the important methods for the land management to understand and accommodate land resources and, for this reason, a key aspect of the T-MAP application too.
It is fulfilled by the T-MAP environment providing new automatic approaches, based on machine learning and image processing techniques, and giving the user the run of the most important GIS tools to handle and query raster and shape data, relate information useful to explain mapped changes and model future land use.
A particular change detection application provided by the T-MAP environment focuses on the road extraction and the following automatic road graph updating. It is possible by means of developed classification and filtering tools and augmenting the input aerial multispectral images by georeferenced ground data acquired by on-board GPS and inertial sensors.
In particular, first, a supervised pixel-based binary AdaBoost technique [3], using a tree classifier as weak learner, allows to categorize pixels into "Roads and bituminous surfaces" and "Other" (Fig.6a). Then, a three-stage filtering (opening, morphological reconstruction and closing filters) is applied to smooth the salt and pepper noise (Fig.6b) and improve the performance of the following tracker reducing the number of false positives.

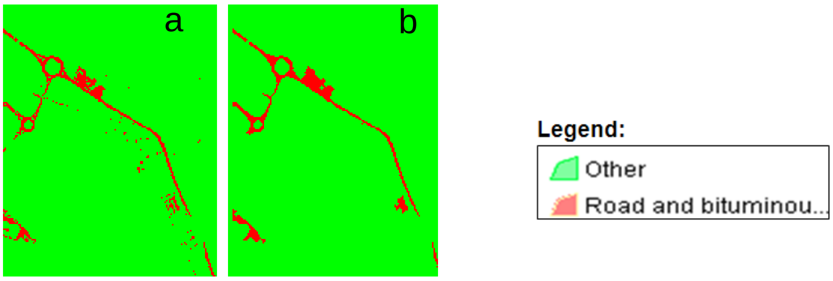
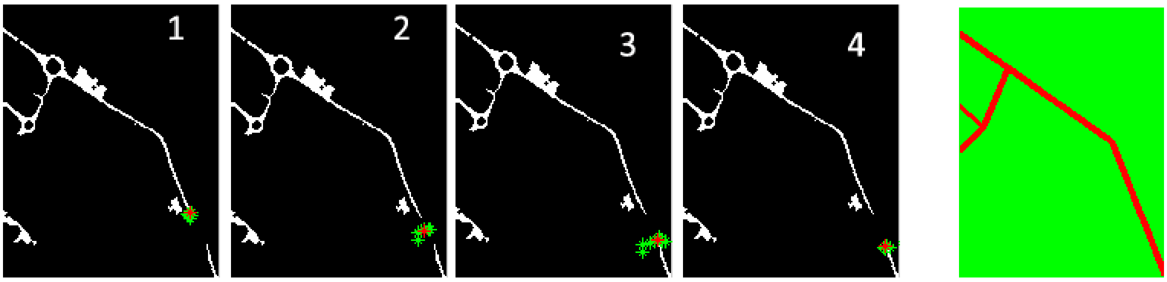


Fig. 6. Pixel-based Classification (step a) and Three-stage Filtering (step b)

Lastly a particle filter, derived from mobile robotics [1], allows to integrate ancillary (old road graph) and vehicle ground data to track road lanes, fastening road ends together and filling road gaps not extracted by the classifier because of occlusions (i.e. shadows, cars, trees).
In Fig.7a an example of tracking and linking between two road segments is shown: in particular the relinking sequence 1-2-3-4 shows how the estimated centerline (red dot, Fig.7a) is able to match the reference one (old graph integrated with ground data, Fig.7b), starting from iterative particles (green dots, Fig.7a).



(a) (b)

Fig. 7. Relinking sequence 1-2-3-4 (a) and Reference graph (b)

4 Conclusion

By using remotely sensed imagery and a hybrid semi-automated classification method, the proposed T-MAP software provide a cost-effective, quick and accurate means to derive land cover information and maintain its currency into the future.
Moreover T-MAP modular structure and its GIS environment allow to enhance and widen its performance in terms landscape monitoring change over time and facilitate its use as a valid GIS decision support system. In particular, the road extraction application here presented is shown to be useful to update old road graphs and automate the change detection problem from multi-spectral aerial data.
The proposed T-MAP package gives comfortable results so that it can be a useful tool for different applications and different decision makers (i.e. urban planner, environmental agencies and so on) could take advantage of it.
Moreover the final products are a GIS-ready maps that can easily enhance other thematic databases.

Reference

[1] Fox D., Burgard W., Thrun S.(1998). *Active markov localization for mobile robots*. Robotics and Autonomous Systems, 25(3-4):195–207, 1998.

[2] Frontoni E., Bernardini A., Malinverni E.S., Mancini A., Zingaretti P. (2009), *Stability maps for really exploitable automatic classification results*, 17th International Conference on Geoinformatics, Aug. 12-19, 2009, Fairfax, USA.

[3] Frontoni E., Khoshelham K., Nardinocchi C., Nedkov S., Zingaretti P.(2008). *Comparative analysis of automatic approaches to building detection from multi source aerial data.* Proceedings of GEOBIA, 2008.

[4] uDiG (User-friendly Desktop Internet GIS): http://udig.refractions.net/

[5] SI^{2}G (Geographical Intelligent Information Systems): www.si2g.it

[6] Zingaretti P., Frontoni E., Bernardini A., Malinverni E.S. (2008), *Automatic Classification of Central Italy Land Cover: Comparative Analysis of Algorithms*, Proceedings GEOBIA2008 “Pixel, Objects, Intelligence: GEOgraphic Object Based Image Analysis for the 21st Century”, ASPRS, ISPRS, CSA-ASC, August 5-8- 2008, Calgary, Alberta, Canada.

[7] Zingaretti P., Frontoni E., Malinverni E.S., Mancini A. (2009), *A Hybrid Approach to Land Cover Classification from Multi Spectral Images*, in Image Analysis and Processing- ICIAP 2009, P. Foggia, C. Sansone, M. Vento Eds., Lecture Notes in Computer Science Series - LNCS 5716, Springer, 500-508, 2009.