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Conclusions and directions for future research

In this work a novel method for the interpretation of multitemporal remote sensing data was developed. In addition, a generic software framework for automatic multitemporal RS data interpretation has been developed.

Two interrelated, specific objectives were pursued: the development of a novel multitemporal classification method that provides for the automatic estimation of its temporal related parameters and for the exploration of temporal knowledge in the classification process; and the design and implementation of a knowledge-based framework for multitemporal interpretation of remote sensing image data.

As a way to validate the new multitemporal classification method, experiments were carried out aiming at the classification of three LANDSAT images of the same region acquired at different years. And as a way to validate the proposed framework, different variants of proposed method were implemented using its temporal knowledge representation and processing functionalities.

Regarding the first specific objective, a new cascade-classification method based on fuzzy Markov chains (FCM) was devised. By taking attributes from two dates rather than one, the FCM-based method uses more information about the object being classified, so that each object can be described by roughly two times as many features as in a monotemporal method. By increasing the dimensionality of the feature space, the demand for training samples for proper parameter estimation also increases, thus, the process of collecting training samples turns out to be more laborious and the whole training procedure becomes more complex in comparison to the corresponding monotemporal approach. Experimental analysis has shown that such additional effort may be rewarded by a noteworthy performance improvement, as long as a significant correlation exists between the temporal data sets. In this sense, the design of the monotemporal classifiers that participate in the multitemporal scheme is a central issue, as it may enhance or mask out the correlation contained in the temporal information.

Performance analysis was conducted upon a sequence of three LANDSAT images from the central region of Brazil using both a stochastic (based on genetic algorithms) and an analytical technique to estimate class transition possibilities. The results showed that the increase in performance is dependent on the temporal correlation between the data sets, as well as on the accuracy of the monotemporal classifiers that take part on the cascade-classification scheme.

While the monotemporal classifiers used in the experiments attained an *average class accuracy* of, in average, approximately 55%, the FCM scheme achieved average performances of around 65%, regardless of the method used for the estimation of transition possibilities. Furthermore, when using the knowledge of the correct classification for one of the considered epochs, the average performance of the multitemporal method raised to around 89%, when using the analytical technique for transition possibilities estimation introduced in this work, and to 93%, when using a stochastic, GA-based estimation technique. It's been argued that the advantage of the stochastic technique in this case has to do with the particular characteristics of the search space. Anyhow, the analytical technique provides an algorithmic rationale onto which hybrid stochastic methods can be structured, further improving the transition possibility estimation process. Comparable results in terms of *overall accuracy* were observed, and this time, the performance improvement was even higher when not using information about the correct classification at any epoch – from 59% with the monotemporal method to 77% with the FCM-based method. Additionally, the proposed method was also compared to two other multitemporal, decision-fusion, cascade-classification approaches, and the experiments showed that under similar conditions, in terms of the available dataset and of the component monotemporal classifier design, the proposed method outperformed the alternative approaches.

The second specific objective of this research was the design and implementation of a knowledge-based framework for multitemporal interpretation of remote sensing image data. In order to achieve that goal, a previously existing framework – InterIMAGE – was enhanced with functionalities that enable it to represent and process explicit temporal knowledge. The interpretation control process of InterIMAGE was extended in such a way that the temporal dimension of an interpretation problem can be explicitly contemplated. Temporal processing steps were included in the control process and temporal operators were designed and implemented. These temporal operators support both the creation of new object hypotheses derived from the hypotheses generated by the interpretation of data from a prior epoch – in what was denoted as the *sequential interpretation strategy*; and the evaluation of hypotheses generated independently for the different epochs, considering the available temporal knowledge – in the so-called *synchronous interpretation strategy*.

In order to validate the extended framework, the FCM-based method was implemented using the framework's new temporal functionalities. A number of experiments in which different variants of the method, structured through the framework, were carried out, and their results were similar to those obtained by performing the same experiments in the environment the FCM-based method was originally created.

This work raises a number of questions for future research.

Regarding the multitemporal framework, other multitemporal classification schemes should be structured onto it as a way for further validation. A possibility in this respect is the method introduced in (Leite et al., 2008), in which hidden Makov models (HMM) were used for the assessment of crop classes in a set of 12 LANDSAT images acquired over a period of three years. The class transition and symbol emission probabilities that compose the HMMs for the different crop classes could be encoded in a knowledge model and processed using the synchronous interpretation strategy.

Moreover, in order to explore the full potential of the framework, it would be interesting to apply it on interpretation problems in which data from different sensors, acquired at different times, would make part of the input data set.

Regarding the proposed FCM-based classification method, further research on alternative implementations for the temporal transformation law could be carried out, particularly considering functions other than the *max* and *product* for the fuzzy s-*norm* and *t-norm* operations. A study of other aggregation functions for the fusion of the monotemporal classification outcomes may eventually lead to more efficient schemes.

It would be also interesting to examine the relative impact of different monotemporal classifier designs on the performance of the multitemporal method. In this respect, for instance, different weights for the membership values computed by the monotemporal classifiers could be considered in the multitemporal model. These weights could be defined as a function of the classifiers' performances, measured over a set of test samples.

Another appealing topic for investigation is related to the length of the image sequence, as the cascade-scheme would probably benefit from the contemplation of a larger set of images from different epochs. Knowledge about the rate of change of landscape objects (if it is stable, increasing or decreasing), could be inferred and explored in the classification process.

Regarding the implementation of the FCM-based method in the multitemporal framework, additional functionalities could be included in the temporal operators in order to provide for the automatic estimation of transition possibilities during (and not before) the interpretation process.

As a final note, the results of this work in terms of the implemented multitemporal framework are available on the Internet – including source code and documentation –, for anyone interested in contributing on its further development, or simply in applying it on particular remote sensing interpretation problems (http://www.lvc.ele.puc-rio.br/projects/interimage).