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J6.2 THE APPLICATION OF SUPPORT VECTOR MACHINES TO ANALYSIS OF GLOBAL SATELLITE DATA SETS FROM MISR

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1. INTRODUCTION

The Multi-angle Imaging SpectroRadiometer (MISR) is one of a suite of five instruments onboard NASA's Terra EOS satellite, launched in December 1999. Typical satellite imagers view the earth from a single direction, but MISR's cameras image the earth simultaneously from nine different directions in four spectral bands. In this way, MISR provides unique multiangle information about solar radiation scattered from clouds, aerosols and other terrestrial surfaces. One of the primary goals of the MISR mission is to improve our understanding of how clouds and aerosols affect the earth's global energy balance.

MISR has now been operational for over four years, acquiring more than 50 Terabytes of high quality data at a resolution of 1.1 km x 1.1 km, with a subset of data at an even higher 275 m x 275 m resolution. In order to make use of this amount of data on a global scale, we have applied Support Vector Machines (SVMs) to MISR imagery classification. SVMs are a type of supervised learning algorithm, in the same category as Artificial Neural Networks, Decision Trees, and Naïve Bayesian Classifiers. Using SVMs, we have developed a global cloud mask, a global cirrus cloud detector and a combination global aerosol detector and classifier.

2. BACKGROUND

This section describes the data available from MISR, other applications of machine learning to satellite image classification, with specific emphasis on cloud detection and classification, and provides a brief introduction to Support Vector Machines and the existing MISR cloud detection algorithms.

2.1 MISR Data

The Terra satellite, which carries MISR, is in a sun-synchronous, polar orbit that crosses the equator every 99 minutes during the descending portion of the orbit at approximately 10:30 a.m. local time. The MISR instrument consists of nine pushbroom cameras with an average swath width of about 360 km (see Fig. 1). The cameras sample data in four spectral bands – blue, green, red and near-infrared – from nine different directions: ±70.5°, ±60°, ±45.6°, ±26.1° and 0° (nadir).

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MISR has a repeat cycle of 16 days, but, because of overlap, the instrument obtains global, multiangle coverage of the entire earth in nine days at the equator and two days at the poles. For more detailed information on MISR see Diner et al. (1998) or the MISR website http://www-misr.jpl.nasa.gov.

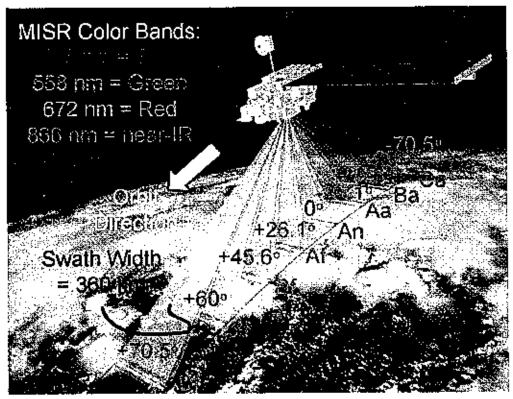

Figure 1. Computer-generated image of NASA's Terra EOS satellite with the MISR instrument onboard. Sampling is as high as 275 m x 275 m per pixel. To reduce the data volume, most images are obtained at a resolution of 1.1 km x 1.1 km. *Image courtesy of Shigeru Suzuki and Eric M. De Jong. Solar System Visualization Project. JPL Image P-49081.*

As MISR passes over the earth, the most forward looking camera (Df +70.5°) images a point 2800 km away from the point imaged by the most aftward camera (Da –70.5°). It takes seven minutes for a point on the surface to be imaged by all nine MISR cameras as the instrument passes over. When the data is processed, the cameras are registered so that each point on the surface is effectively seen from nine different viewing directions by a "virtual" MISR instrument (see Fig. 2). In actuality, the cameras are registered either to an idealized earth "ellipsoid" or to terrain provided by a digital elevation model (DEM). Because they are physically closer to the instrument, objects above the surface, such as clouds and some types of aerosol, appear to move relative to the surface from one camera to the next due to the effect of parallax.

The processed MISR data is stored in Hierarchical Data Format (HDF) and is available from the NASA Langley Research Center Atmospheric Sciences Data Center.

2.2 Other Applications of Machine Learning to Satellite Cloud Imagery Classification

Beginning as early as Shenk et al. (1976), artificial intelligence methods have been applied to the problem of cloud detection and classification in satellite imagery. Computer pattern recognition was used by Ebert (1987), Garand (1988) and Ebert (1989). Neural network approaches, by far the most popular, were adopted by Key et al. (1989), Lee et al. (1990), Peak and Tag (1992; 1994), Bankert (1994), Bankert and Aha (1996), Miller and Emery (1997) and Tian et al. (2000). This list is by no means exhaustive. Usually these artificial intelligence approaches have been applied only to a small range of scenes or within a geographically limited region. Few artificial intelligence methods have been applied to global satellite data.

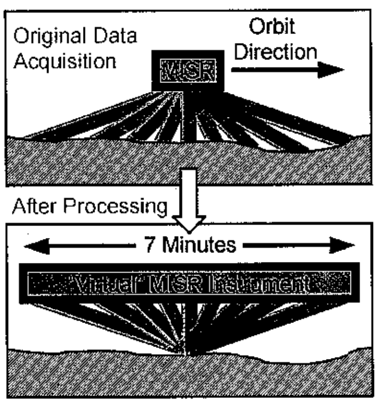

Figure 2. When data is initially acquired, each MISR camera views a different portion of the earth. After processing, all nine MISR cameras are registered to the same point on the surface.

2.3 Support Vector Machines

Support Vector Machines are similar to other supervised learning algorithms (Artificial Neural Networks, Naïve Bayesian Classifiers, etc.) in that they learn to classify new data based on fully labeled training data. In the applications discussed here, SVMs have been used to classify individual pixels in MISR images. Each pixel is classified using "feature vectors" that incorporate information from multiple MISR cameras and spectral bands.

This paper is not an introduction to SVMs; for the purposes of this discussion SVMs can be considered to be "black boxes" that take labeled feature vectors as input and produce deterministic classification algorithms that can be applied to classify feature vectors from novel data. Readers who are interested in the details of SVMs should refer to Cortes and Vapnik (1995) or the excellent website http://www.kernel-machines.org for more information.

Most of the techniques used to develop the MISR classifiers described here could be applied equally well to any other supervised classification technique. However, SVMs have some important properties that make them an appropriate choice for this type of work. First, the SVM training algorithm is deterministic and avoids becoming trapped in local minima during optimization. Second, the training algorithm inherently incorporates a technique to balance maximal accuracy with maximal generalization performance. While not a panacea, this does help to mitigate problems of overfitting often seen with other learning classifiers (Schölkopf and Smola 2002). Finally, because SVM training depends only on the distances between feature vectors, which can be computed in a single preprocessing stage that is inherently parallelizable, it is possible to explore very large feature vectors (hundreds of features), making the difficult feature selection stage less important.

2.4 Existing MISR Cloud Detectors

Cloud detection and screening are important for the MISR mission's scientific objectives, some of which require accurate retrievals of aerosol and surface properties. Three cloud detectors – called cloud "masks" – have been developed by the MISR science team specifically for use with MISR. These cloud masks are designed to classify each 1.1 km x 1.1 km MISR pixel individually as either cloudy or clear, with high confidence or low confidence.

The Radiometric Camera-by-camera Cloud Mask (RCCM) uses the mean and variance of the red and near-IR radiances from each of MISR's nine cameras individually to identify cloudy and clear regions. A statistical method provides dynamic thresholds that separate cloudy pixels from clear pixels based on the input data (Diner et al. 1999b). As shown in Fig. 3 the RCCM is extremely accurate over water, where good thresholds have been implemented. However, the RCCM is less reliable over land, where the thresholds are still in the development stage. Additionally, the RCCM has difficulty correctly classifying specular reflection from bodies of water, commonly called "sun glint" or "sun glitter." For this reason, a conservative, geometrically derived "glitter mask," specific for the geometry of each camera, is used to designate areas in an image where sun glint might be expected to cause problems for the RCCM retrieval.

The Stereoscopically Derived Cloud Mask (SDCM) takes advantage of MISR's multiangle capability. A feature matching algorithm is used with combinations of MISR's cameras to determine the height of observed reflecting surfaces (Moroney et al. 2002). If this height is greater than the height of the terrain at that location, given by the digital elevation model, then the associated pixel is assumed to be cloudy (Diner et al. 1999a). Figure 3 shows that the SDCM is only slightly less accurate than the RCCM, but the SDCM performs equally well over land and water. However, there are times when the feature matching algorithm is unable to find a satisfactory match between features in multiple cameras. This can occur, for example, when clouds in