Snow cover monitoring with images from digital camera systems

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Abstract
Snow cover extension is one of the most important parameters for the study of climate variations, of hydrological balance and also for the management of touristic activities in mountain areas. Recently, webcam images collected at daily or even hourly intervals are used as tools to observe the snow covered areas; those images, properly processed, can be considered a very important environmental data source. This paper presents the Snow-noSnow software specifically designed to automatically detect the extension of snow cover from webcam images. The software was tested on images collected on Alps (ARPAV webcam network) and on Apennine in a pilot station properly equipped for this project by CNR-IIA.
Keywords: snow cover monitoring, digital images, software, Alps, Apennines.

Introduction
The seasonal snow cover represents one of the most important land cover class in relation to environmental studies in mountain areas, especially considering its variation during time. The snow cover and its extension play a relevant role for the studies on the atmospheric dynamics and the evolution of climate and also on the analysis and management of water resources. Moreover, in mountainous areas snow represents a relevant economic resource for the winter tourism. Considering all these elements, it is clear that monitoring the snow cover state improves the scientific knowledge on the meteo-climatic phenomena and plays an important role for the sustainable management on the mountain territory and its resources.
Typically, the snow monitoring is performed through traditional systems like the weather stations scattered on the territory [Cagnati, 2003], automatic snow height sampling stations using probes [Cagnati, 1984] or digital cameras [Gook-Hwan et al., 2007], products derived from satellite images [Casacchia and Salvatori, 2006; Salvatori, 2007; Salzano et al., 2008]. Satellite images like those from NASA-NSIDC (http://nsidc.org/) and NOAA-IMS (http://www.natice.noaa.gov/ims/) are also used for snow cover daily monitoring at regional scale [Cianfarra and Valt, 2009; Spisni et al., 2011]. Detailed investigations would require higher spatial resolution sensors but the revisit time of those sensors is often incompatible with the

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snow persistence at soil. Thus images captured by digital cameras become a useful tool at local scale providing images even when the cloud coverage makes impossible the observation by satellite sensors. Recently, images taken using digital cameras have been used since they collect data with a high temporal and spatial resolution at low cost [Hinkler et al. 2002]. Hinkler et al. [2003] have used multispectral images (green, red and near infrared-NIR) taken using a fixed camera shooting a coastal area in Arctic region (Ny Ålesund, Svalbard), in order to monitor albedo variations of the snow cover during the melting period. In mountain regions, Corripio [2004] have used long shot of the Mer de Glace (Mont Blanc), taken with different field of views (6 megapixel camera) to evaluate the extension of the seasonal snow cover. The images that have been analysed in the abovementioned papers, have been taken manually and within a limited period of time. These observing techniques performed using photo cameras in relation to specific research projects have a limited importance when applied to environmental monitoring, especially when dealing with the study of climatic variations where extended data and images- series represent the real added value as shown by Buus-Hinkler et al. [2006] who have used images captured by a fixed camera and Landsat TM images to monitor the relationship between snow and vegetation covers in the Arctic environment.

In this perspective the networks of cameras, especially those with a fixed long shot, started to play a relevant role in an environmental perspective. During the past 10 years, in the Alpine region many webcams have been installed and their images have been mainly used for touristic purposes and to a very limited extent for environmental monitoring or in order to provide support to snow field observations.

When suitably processed these images can be used for scientific purposes, having a good resolution (at least 800x600x16 million colours) and a very good sampling frequency (hourly images taken through the whole year). When stored in databases, these images represent therefore an important source of information for the study of recent climatic changes, to evaluate the available water resources and to analyse the daily surface evolution of the snow cover. One of the most important webcam network within the Italian Alps is the one managed by ARPA Veneto, implemented in 1999 with the financial contribution of the InterReg II Italia-Austria Programme "*AVEN 331010 - Produzione e diffusione congiunta dei servizi meteorologici a supporto delle attività turistiche delle Alpi orientali*". The images from the network are being exploited by the personnel charged of weather and avalanche forecasting in order to perform a visual monitoring of the territory in the Arabba Avalanche Center (cfr. http://www.arpa.veneto.it/csvdi/svm/webarpav/index.html).

Recently, many webcam have been installed along the Apennines (http://www.meteoappennino.it/index.php?option=com_webcam&Itemid=86). They are mainly devoted to have an overlook on the snow cover condition for touristic and recreational use. Cameras located in the monitoring stations are programmed to take hourly pictures every day. Due to the high number of collected images there was the need to make available an autonomous tool to handle such a large image database performing a detailed analysis of them. In order to obtain quantitative information on the snow cover directly from images, the Italian National Research Council – Institute for Atmospheric Pollution Research (Monterotondo-Rome) and ARPA Veneto-Arabba Avalanche Center (CVA) have agreed to collaborate in order to develop a common project, called Snow-noSnow.

This project has the goal of monitoring areas at different scales, particularly analysing areas close to the camera and with homogeneous land features in order to obtain information on the snow presence/absence, its persistence and distribution within the examined area. One of the first results of this project is the development of a dedicated software for the snow cover analysis through the processing of images taken from webcams and fixed or mobile digital cameras.

The monitoring network

The monitoring equipment installed in two different places in Alps and Apennines is provided by Sistemi Video Monitoraggio S.r.l. (Romito Magra-SP) and is equipped with a high resolution digital camera (Canon Powershot SX110 IS, 1/2.3" CCD, 3456x2592 pixel, 6mm objective - 35 mm equivalent focal length of 36mm), a specific hardware for data logging and transmission, placed into a waterproof case, a power supply unit using AC or photovoltaic panels with a buffer battery. Data transfer is performed using an intranet connection with the receiving station located in Arabba through a fax/modem GSM connection. In the Apennine station, due to the lack of GSM connection, data are stored locally and automatically copied on a backup hard disk. The system is controlled by the VM95 software, developed by SVM S.r.l. and Erdmann Video System [Valt, 2002].

The ARPAV station

For the present work the images taken from the camera of the Cima Pradazzo station (Falcade), (46°21'24"N, 11°49'20"E) have been used. This station is located at 2200 m asl in the Dolomites. The field view of the camera ranges from a medium shot looking at the TreValli ski runs to a long shot on the northern part of the Pale di San Martino, the Cime del Focobon (3054 m) and Monte Mulaz (2906 m). The choice of this field of view is related to the different kind of snow represented into the image that ranges from untrampled to groomed snow; the areas in the long shot remain covered by snow for a long time.
The camera is installed close to the snow monitoring station of Cima Pradazzo, equipped with snow and weather sampling and monitoring instruments, between the others snow height, internal and surface temperature sensors.

The CNR-IIA Apennine station

In order to make available a series of images of an area in the Apennines, a brand new experimental station has been conceived and implemented by CNR-IIA in the territory of the Monti della Laga - Gran Sasso-Monti della Laga National Park. The station is located along the S.S. 260 "Picente" just after the km 11,500; the camera is mounted on the east side of a building belonging to the Municipality of Amatrice (Province of Rieti) that make it available to CNR (42°35.396N, 13°19.787E, 1300 m a.s.l.). Close to the CNR-IIA station, a manual seasonal weather monitoring station is located in an area called Peschiere (42°60N 13°33E, 1270m asl); it is handled by the Meteomont Service (State Forestry Corps); data collected only during winter are available on the web. CNR-IIA is going to install an automatic meteo station close to the camera. The station is equipped with the same digital camera, hardware and software of the ARPAV stations.
The study area is located on the right bank of the Fosso Cerruglia; it is a slight slope, characterized by a xeric grassland. The area is easily reachable and scarcely frequented, it represents a very good point for the observation of the snow cover and the natural vegetation. In the images the mountain chain of the Monti della Laga comprised between Monte Gorzano (2458 m) and Cima della Laghetta (2369 m) is distinguishable.

The Snow-noSnow Software

The software Snow-noSnow has been appropriately developed in order to support this activity; it identifies the extension of the snow cover as shown in the images automatically taken with a very limited human intervention. The software architecture is based on different functions representing the preparatory steps of the main processing routine. Snow-noSnow is handled through an interface where the images to be processed and the 'mask' to be applied for the analysis have to be selected. The mask can be easily prepared using any drawing software. The areas covered by the mask must be homogeneous; the possibility to handle a single or multiple masks solves the problem of studying areas with different land features. The software is able to handle a single or multiple masks. A single mask typically covers a large part of the image where only the sky and areas at a distance are excluded. The multiple masks are useful when it is important to analyse different parts of the image with different surface characteristics. The software has an additional feature, it could select a set of images to be processed, as specified by date and hour of the capture (Fig. 1).

Each time an image is processed, a specific function is activated; it performs a series of validations, identifying the images to be rejected due to malfunctions or to bad weather conditions (heavy snowfall, rainfall or fog). Bad images are identified through a statistical analysis of RGB values throughout the whole image and are excluded from the processing steps. The core function of the software is based on a binary snow-no snow classification algorithm that allows the real identification of snow covered surfaces. The procedure foresees a statistical analysis of RGB values of all pixels in the mask and allows, using mathematical criteria, to identify a threshold value to be linked to the snow cover thus allowing its detection. The classification procedure is based on statistical criteria and does not require human intervention other than the initial selection of the dataset. The flexibility of the selection of different parts of the image, through the use of different masks, makes possible to evaluate different part of territory having different land features. Images are processed according to the following steps. The jpg image is separated into its RGB components; for each part of the image inside the predefined mask the Digital Number (DN) frequency histograms are calculated. A smoothing function is applied to the frequency histogram of blue component calculated as an average of the 5 nearest points. It is clear that the DN frequency distribution within the area inside the mask will be different according to the amount of snow-covered pixels. A preliminary statistical analysis, prior to the definition of the algorithm was performed analysing around 300 images captured in both areas. It showed that the blue component corresponding to snow covered areas is always ≥ 127. The histogram of the values inside the masks shows a bimodal distribution in 90% of cases; when snow is totally missing the histogram is shifted to low DN values, in case of high snow coverage it is shifted to highest values (this occurs in all the three components).

To consider the DN frequency distribution, the value of x-axis corresponding to the first local minimum beyond $x \geq 127$ is selected as the threshold value for image classification. When there are no local minima the DN=127 is selected as the threshold value. When the blue component obtained from a jpg image is processed, snow always shows higher values also and mainly in the shaded areas. In fact, in the blue wavelength range, snow cover presents reflectance values always >0.8 [Salvatori, 2007], which are significantly higher than those measured on other types of natural surfaces. Therefore during the classification procedure only the blue component was chosen, thus reducing by one third the processing time.

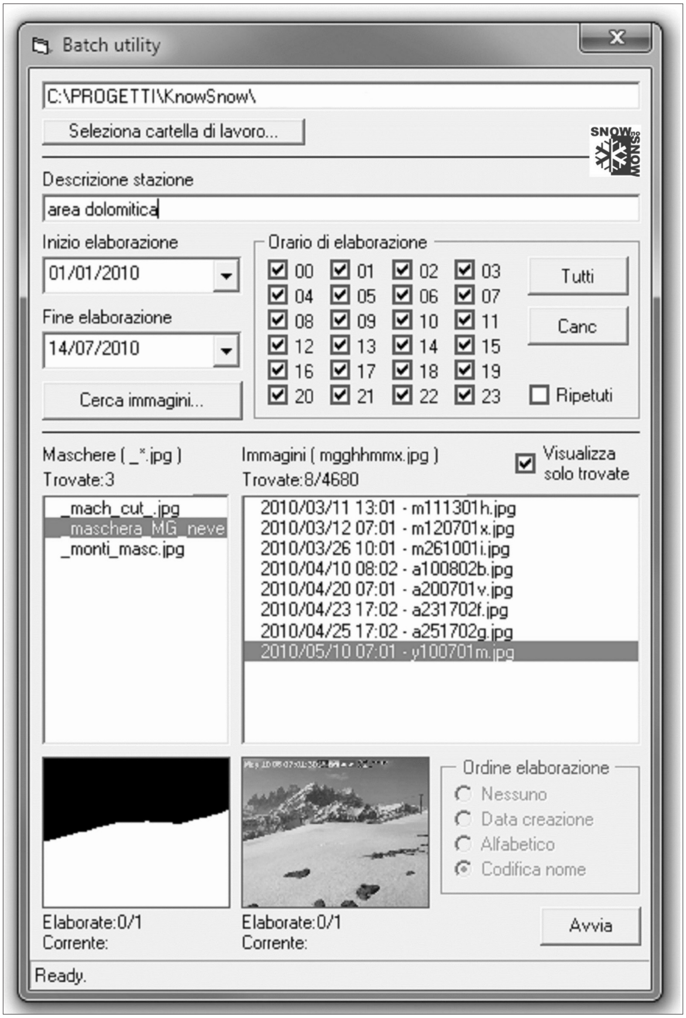

Figure 1 - Screenshot of the Snow-noSnow input interface.

Anyway, applying the same procedure to the three components the same results are obtained: the unclassified pixels percentage variation is always lower than 1%. Once the software was compiled, the resulting classifications were compared with those obtained by photointerpretation and by a segmentation image routine implemented in ENVI. This last procedure allow us to segment the image into areas of connected pixels based on a defined range of DN values. For each image the DN values were manually selected from DN frequency distribution as well as automatically calculated by Snow-noSnow. The average discrepancy between results automatically obtained from Snow-noSnow and those obtained running the ENVI segmentation routine for each image, is lower than 0.5%. The difference is mainly due to how the algorithm identifies the pixels to be connected. Being the difference negligible, a comparison with the original image was performed based on visual interpretation; for example considering a 100% snow-covered image, 2-3% of snow-covered pixels is not detected by the software due to the presence of shaded snow-covered associated to the surface roughness.

There are two different modes to use the software in order to calculate the snow cover surface extension. In the first mode the image is analysed in order to obtain a percentage value of the snow cover referred to the pixel number. In this case it is sufficient to make available an image and the mask corresponding to the investigated area. The second mode requires a more sophisticated elaboration that, taking into account the land features and the camera field of view, could provide as a result a percentage value correlated to the actual area expressed in square meters. In this case it is mandatory to use images that can be corrected according to specific coefficients calculated for the topographic features and acquisition geometry of the observed area. The following are the preliminary procedures to adopt for the creation of a weighted mask:

- correction of the image optical deformation. Typically this correction is performed taking into account the CCD size and the focal length of the camera objective [Corripio, 2004];
- creation of a digital elevation model (DEM);
- image rectification;
- superimposition of DEM on top of the rectified image;
- definition of the number of pixels for each element of the DEM grid;
- calculation of the ratio between surface unit of each element of the DEM grid and the number of pixels occurring in the same element;
- provide to each pixel a surface value derived from the size of each element of the DEM grid. Creation of a 'weighted mask' where each pixel into the mask has its own surface value.

At this point the software is capable to process the image, using the abovementioned routine, providing a value corresponding to the amount of the snow cover into the study area. The output of Snow-noSnow is represented by:

- the frequency histograms for each of the three components, where the threshold used to identify the considered pixels is highlighted;
- the resulting image showing the pixels classified as 'snow';
- the value corresponding to the percentage of 'snow' pixels compared to the total amount of pixels into the mask (mode 1) and/or the surface snow covered area value (mode 2).

When more images are being processed the output file contains threshold value and pixel percentage values for each of the analysed images. These output features allow to follow the trend of the snow cover relying on quick processing times being thus useful for people collecting field measurements.

Results

The analysis of images captured by monitoring stations during the past 3 years in the Alps and last year in the Apennines shows the capabilities of the Snow-noSnow software to follow in detail the seasonal and daily evolution of the snow cover. The processing procedure has been applied to images taken at the CNR-IIA Apennines station where a DEM of the medium shot area was made available after a topographic survey having the position of the camera as the reference point. In the Apennines area where snow cover variation could be

sudden, the software was particularly effective. The analysis of the hourly images taken at the CNR-IIA station shows how in less than 24 hours the snow cover could vary from 0 up to 85% and then back to 0. This shows how meaningful is the variation of snow persistence at soil in the Apennines. Data that will be collected at the CNR-IIA station in the coming years would represent a meaningful element for the climate studies at local level. The added value resulting from this analysis and estimation of the snow cover is particularly relevant during the deposition and melting phases. During these periods, only punctual data are collected by traditional instruments and used for different analysis (avalanche forecasts, estimation of snow water equivalent, dynamics of snow as related to river runoff). As shown by the analysis of images of Alpine areas, information provided by Snow-noSnow will compensate the potential estimate errors associated to the snow cover thickness values measured by a snow gauge. During a melting period, in fact, snow can be discontinuously distributed on the surface and a snow gauge is only able to detect snow thickness at one point as occurred in Cima Pradazzo on May 16th 2008 (Fig. 2a).
The spatial analysis performed with Snow-noSnow expressed as a percentage of snow covered pixels, shows an ablation trend going beyond May 15th. The same occurred during the ablation phase both in 2009 and 2010 (Fig. 2b, 2c).
Since the software allows to analyse different parts of an image, it is possible to take advantage of this feature applying it to a mask corresponding to areas that could be considered an infinite distance away. Knowing the extension value of these areas in square meters it is possible to estimate the surface of snow covered areas also without a DEM simply converting the percentage of pixels expressed by the software into a percentage of square meters into the mask. The images taken in Cima Pradazzo could be analysed to monitor the snow cover using different masks corresponding to different altitude belts. The information about the snow coverage in the studied areas were successfully used by snow technicians to scheduled theirs surveys.

Conclusions and further developments

Images taken from fixed digital cameras could be very useful to monitor snow covers while they provide data collected continuously, under controlled conditions and also in cloudy conditions.
Taking as true data coming out from photointerpretation, results show that using Snow-noSnow only 1% of pixels is misinterpreted.
The results obtained through the use of Snow-noSnow are thus comparable to the one achieved by photo-interpretation and could be considered as better than the ones obtained using the image segmentation routine implemented into ENVI. Additionally, Snow-noSnow operates in a semi-automatic way and has a reduced processing time.
The analysis of this kind of images could represent an useful element to support the interpretation of remote sensing images, especially those provided by high spatial resolution sensors.
The foreseen improvements would provide unbiased information about some parameters relates to snow cover expressed until now by subjective evaluations, in order to study the effects of the wind at high altitudes [Sung-Hyun et al., 2007].
It is foreseen to implement a routine for the estimation of the snow volumes to be used into the models for the calculation of snow water equivalent.
From the instrumental point of view, it is currently undergoing a testing for the analysis of snow surface features variation through NIR images.

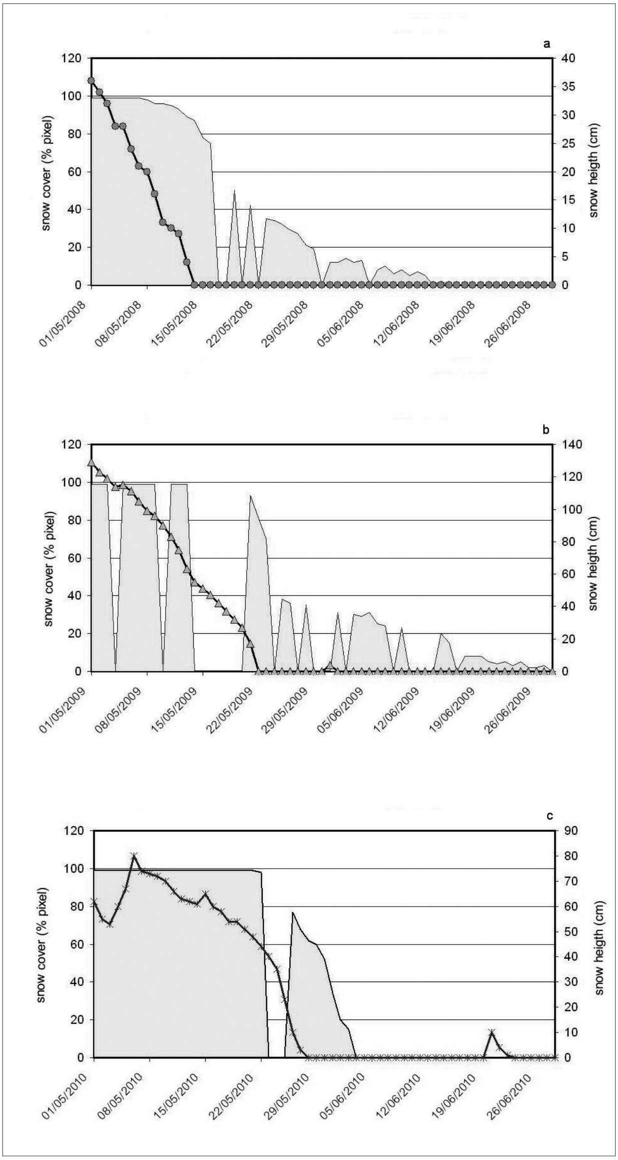

Figure 2 - Snow cover percentage calculated with Snow-noSnow on the image of Cima Pradazzo and snow heigth measured by the snow gauge during three different yearly ablation period (a-2008; b-2009, c-2010). The spatial analysis performed using Snow-noSnow shows the presence of snow covered areas also when the values of the snow gauges indicate the absence of snow.

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