Automated Visual Snow-Cover Measurement Using SRG and VMS

Gook-Hwan Kim, Sungsoo Rhim, Soon-Geul Lee

Abstract—**In this paper an automated snow-cover measuring system is developed, which analyzes the visual image of drifted snow and measures the height of snow-cover. The system consists of a measuring ruler, a CCD camera (including infra-red module), and a PC which executes image processing, logs data and transfer the information to remotely located users via internet. The snow-depth is estimated based on the position of the lowest uncovered marker on the ruler which is estimated from the captured image. The distortion in the captured image is calibrated by an expansive coefficient curve and the calibrated image is compared to a virtual measuring scale (VMS) for the accurate measurement. To detect the boundary of the snow-cover the seed region growing (SRG) algorithm is used. To enhance the visual measurement process, the captured images are pre-processed and the camera is calibrated for various weather conditions. The measurement system can also transfer the raw images as well as the estimated snow-depth in real-time to a remotely located client through internet. Experimental results show that the system improves the reliability and the accuracy in measurement as well as the convenience.**

Index Terms—snow-cover measurement, virtual measuring scale, calibration of distortion, SRG algorithm

I. INTRODUCTION

Generally the locations whose snow-cover condition is our keen interest are the recesses in the countryside that are mountainous and difficult to approach due to the piled snow. The traditional way of snow cover measurement is to get to the target location and measure the height of snow-cover with the eye against the mark on a vertical ruler mounted on the ground [1].

With the development of technology in sensor and measurement more accurate and convenient ways of snow-cover measurement have been introduced [2][3]. The balance for measuring amount of precipitation (BMAP) and the depth-of-snow-cover meter (DSCM) are the examples. The BMAP measures the snow-cover depth by converting the mass of the precipitation to the height of snow. This type of measuring device is prone to result in unreliable measurement due to the inclusion of foreign materials such as leaves, dirt, and so forth. The DSCM uses the ultra-sonar signal to measure the distance from the ultra-sonar signal emitter to the surface of the snow cover. This type of measuring device, however, results in false measurements when alien objects obstruct the propagation of the ultra-sonar signal.

To improve the performance and enhance the convenience of measuring and monitoring processes the current paper has developed an internet-based automated visual snow-cover monitoring and measuring system, so-called Cliview-High, where a CCD camera installed locally captures the images of the vertical measure ruler buried under snow. The captured images are then transferred through internet in real-time to users located remotely. The user can read off the mark on the ruler from the captured images or the Cliview-High system can automatically process the images to estimate the snow-cover depth.

Although the remote accessibility through internet in Cliview-High enhances the promptness in preparing for the possible climatic disasters, there are many problems in measuring the snow-cover depth based on the images acquired by a camera. With clean daylight, it is easy to read off the mark on the ruler with naked eyes. But at night it is difficult to identify the boundary between the covered and the uncovered regions of the ruler. Adding more light would introduce other drawbacks; the ambient light intensity, the exposure compensation, and so forth. Moreover, the captured image is inevitably distorted by the camera lens and in order to obtain accurate measurement based on the image it is required to calibrate this distortion.

Cliview-High system processes and analyzes the captured images to extract as accurate as possible information about the snow-cover. It generates a virtual measuring scale (VMS), which is compared with the image to measure the snow-depth automatically.

To measure the snowfall in the image using the vision system, a segmentation method is chosen. For the segmentation of intensity images, there are four main approaches, namely, threshold techniques, boundary-based methods, region-based methods, and hybrid techniques. Threshold techniques are based on the postulate that all pixels whose value lie within a certain range belong to one class. Boundary-based methods use the postulate that the pixel values change rapidly at the boundary between two regions. Region-based methods rely on the postulate that neighboring pixels within the one region have similar value. This leads to the class of algorithms known as region growing of which the "split and merge" technique is

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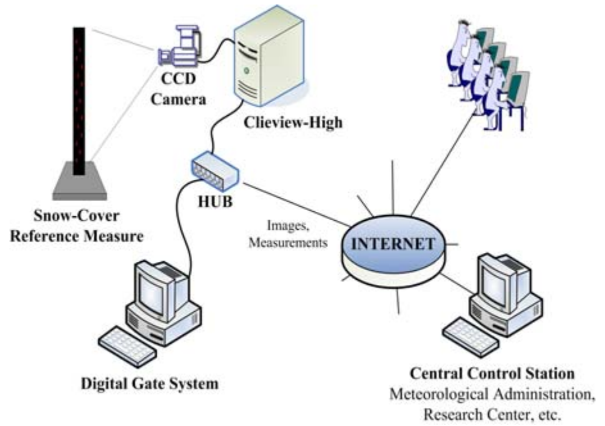


Fig. I Configuration of Cliview-High.

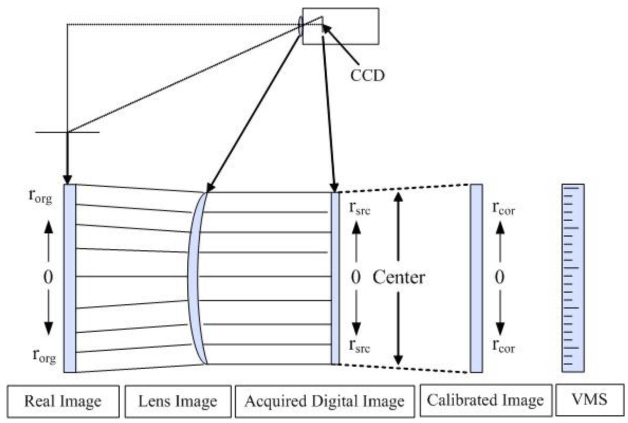


Fig. II Calibration of distorted image taken by CCD camera.

probably the best known. The hybrid techniques are to combine boundary and region criteria [5][6].

The following sections of the paper explain the details of the image processing approaches and the use of VMS in Cliview High. Section II explains the general configuration of Cliview High and Section III illustrates the calibration of the images and the use of VMS and the automated detection of the surface of the snow cover as well as pre-processing before the application of the SRG algorithm.

II. System Configuration

Fig. I shows the configuration of Cliview-High. Cliview-High consists of a snow-cover measuring ruler, a CCD camera attached to a main control unit on a PC. The ruler is a 1.5 meter cylindrical structure installed in the local instrumental shelter. It is coated with chemicals to minimize the adhesion of snow. The infra-red lighting module is also installed in the shelter to adjust the intensity in night time. Initially the conventional outdoor lighting system has been used with a typical CCD camera. This approach, however, has caused complains from the neighbors and a more focused infra-red lighting with an infra-red camera filters are used in residential areas. The distance between the CCD camera and the measuring ruler is 4m and the ruler has a full south aspect.

The CCD camera captures the image of the uncovered ruler along with the circumference of the ruler. From the captured images the image processing unit determines the depth of the snow-cover. The operation of the CCD camera and the lighting system can be remotely controlled by the user. The central control unit includes a internal-based image transport system that transports in real-time the images taken by the CCD camera via network or internet.

The measurement of the piled snow can be performed either automatically at a pre-set rate or manually by the operator located remotely.

III. Visual recognition algorithm

There are two main requirements of the image processing algorithm in Cliview-High. The first is to calibrate the image that is distorted by the refraction of light. The second is to detect the surface of the snow-pile in image and estimate the actual depth of the snow in the calibrated image. This section explains the details of two processes that are designed to satisfy the two requirements. For the calibration of the image, the authors have taken the well-known expansive correction curve approach. After the calibration, the calibrated image is to be compared to a so-called virtual measuring scale (VMS) for the estimation of the actual depth of the snow cover.

A. *Calibration and Virtual measuring scale (VMS)*

The image taken by the CCD camera is distorted by the refraction of light and does not exactly represent the actual scale of the subject pictured. This divergence from the rectilinear projection is called barrel distortion. As illustrated in Fig. II, the barrel distortion causes the image magnification to decrease with increasing distance from the optical axis (or the center of the image). The divergence will result in a critical error in measurement of snow-cover depth based on the captured image.

The calibration approach taken in Cliview-High is to expand the distorted image using an expansive correction curve function, where each pixel in the captured image is shifted radially. The correcting function used in this work which determines for each pixel the distance to be shifted by is a third order polynomial. It relates the distance of a pixel from the center of the source image r_{src} to the corresponding distance in the corrected image r_{cor} :

$$r_{src} = (a \cdot r_{src}^3 + b \cdot r_{src}^2 + c \cdot r_{src}^3 + d) \cdot r_{cor} \qquad (1)$$

The parameter d represents the linear scaling of the image. A set of parameters d = 1, and a = b = c = 0 leaves the image as it is. The parameters a, b and c distort the image. If we do not want to scale the image, we can correct the image through the set d so that a + b + c + d = 1.

The correcting parameters are specified for each camera lens and can be used for all the images taken by the particular lens. In this work, the correcting parameters are experimentally obtained from a set of reference points evenly spaced (10cm

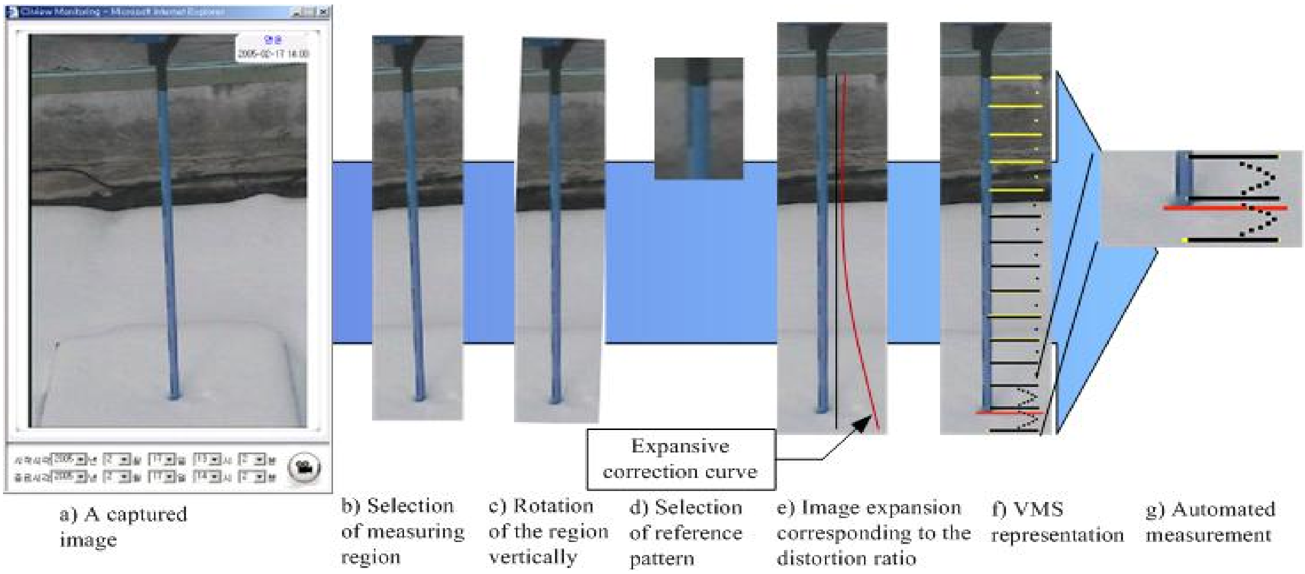


Fig. III VMS generation process.

apart to each other) in the actual measuring ruler.

During the process of barrel distortion calibration, a so-called virtual measuring scale (VMS) is established on the calibrated image. The VMS is obtained by experimentally comparing the distance between pixels in the calibrated image to the actual distance in the measuring ruler. The calibrated image accurately represents the rectilinear projection image of the subject (or the actual measuring ruler with snow cover), the VMS should be obtained by the linear scale factor between the actual distance and the image

Fig. III shows the steps of image processing for a given source image. At first, from the image acquired by the CCD camera using Cliview-High system a region of our interest for the snow-depth measurement is clipped off. Then the clipped image is rotated to make the projection of the measuring ruler to be vertical. This process plays an important role in decreasing the error that would be result in otherwise during the application of VMS to the calibrated image. Next step is to expand the source image to a calibrated image. During this step the pre-acquired correction function shown in (1) is used. In the Fig. III (e), the correction curve is illustrated. The VMS is indicated on the expansive image and makes it possible to read the scale of the image. Finally, the VMS overlays on the top of the calibrated image and it shows the actual distance between the pixel points.

The VMS can be used for both manual and automatic measurements of the snow-depth. For the manual eye-measurement, image can be zoomed in and the VMS will be linearly scaled according. In the zoomed and calibrated image, the user locates the surface of the snow pile and read the height of the snow-depth against the VMS. The automated measurement method similarly uses the VMS like the eye-measurement, but requires one more technique to automatically search the surface of the snow-cover. Fixed SRG (Seeded Region Growing) algorithm is used for this purpose.

B. Fixed SRG (Seeded Region Growing) segmentation

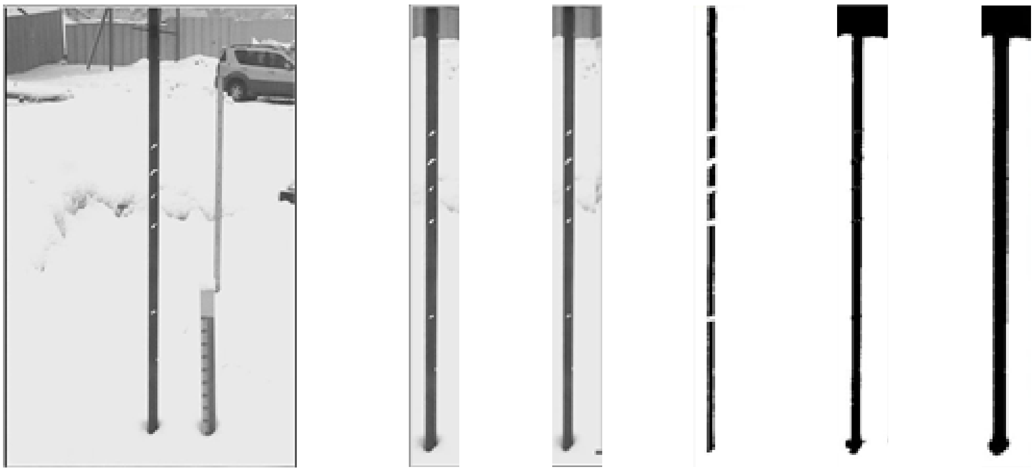
Seeded region growing (SRG) algorithm was initially proposed for static image segmentation [5]. This approach is a sequential labeling technique starting from picking the initial seeds. Given the seeds, SRG tries to find an accurate segmentation of images into regions with the property that each connected component of a region meets exactly one of the seeds. In the growing process, the pixels neighboring to the seeds are merged to the seeds iteratively based on certain criterion [4][5].

The segmentation techniques yield raw data in the form of pixels along a boundary or pixels contained in a region. Although these data sometimes are used directly to obtain descriptors for the region boundary, the standard practice is to use schemes that compact a data into representations that are considerably more useful in the computation of descriptors. In many techniques, we use the chain codes to represent a boundary. Typically, this representation is based on 4 or 8 connectivity codes [6].

The first step in the SRG process is to determine the initial seed points. In this application, it is known that pixels of the measuring ruler tend to have the minimum allowable digital value. Based on this information, we selected as starting points all pixels that have values of 0 (black).

The next step is to choose criteria for region growing. In the paper we chose two criteria for a pixel to be annexed to a region.

(i) The absolute gray-level difference between any pixel and the seed has to be less than a threshold value. The threshold value is used to test the pixels in an image which has been processed by a contrast stretching transformation. This transformation is to increase the dynamic range of the gray levels in the image being processed. Before this transformation, the image is filtered by noise reduction



(a) (b) (c) (d) (e) (f)

Fig. IV Pre-processing of image and region-merging for SRG algorithm: a) converted gray-level image, b) image of ROI filtered by a median filter, c) image after blurring, d) image after region-merging process with threshold = 2 pixel-distance, e) image after region-merging process with threshold = 10 pixel-distance , f) image after region-merging process with threshold = 20 pixel-distance.

processes; median filter and blurring.

ii) A pixel is compared to its four neighboring (top, down, left, right) pixels. For a pixel to be included in one of the regions, the difference of grey scales of the pixel and the neighboring pixels has to be within the threshold. If a pixel is found to be connected to more than one region, the regions are merged.

Another important criterion considered in the paper is about how to merge separated regions. The reason why we need to consider this criterion is illustrated in Fig. IV. Figure IV (a) shows a raw image of the measuring ruler captured on a snowy day. A few white marks on the black ruler in the center of the image are the traces of snowflakes fluttered in the air. Even after a series of pre-processes the white traces of snowflakes remain and, as shown in Fig. IV (d), they divide the black ruler image into several regions. In order to ignore this kind of undesirable disturbances caused by any flying small objects and increase the robustness of the measurement, we have adopted a region-merging criterion. If two or more regions with the same properties are separated by a certain pixel-distance, we merge the regions into one.

The selection of the threshold distance value for region-merging process brings about a trade-off problem in balancing between the robustness and the accuracy of the measurement. If the threshold distance is too small as in Fig. IV (d) the noise can not be properly removed. On the contrary, if the threshold distance is too large, then we would include a farther noises into the region of our interest and the measurement of the snow-depth could be far off from the real value (Fig. IV (f)). To compensate the effect the external obstacles, an optimal threshold value (10 pixel-distance) for the region-merging process is obtained from a fairly long period of field-tests (Fig. IV (e)).

The process of the SRG algorithm starts from a seed point on the top of the black measuring ruler in the captured image and grows the region downward to the region boundary where the black ruler meets the snow-cover. After the SRG process, the boundary between snow-cover and the uncovered scale is automatically searched for. The snow-cover depth is then estimated by comparing the pixel information of the boundary to the physical distance information stored in the virtual scale measure (VMS). Figure V shows the graphical user interface where the process of SRG and comparison to VMS is displayed. In the figure, VMS which is displayed as a set of white lines with labels is compared with the boundary line in the image. The comparison to VMS can be done either automatically or manually by the observer.

C. Pre-processing and Processing

Figure VI shows all the image-processes performed in the automated measuring task. All the processes are executed in the computer located at the target location where the measuring

(a) day (b) night (with infra-red module)

Fig. V Pictures of GUI displayed on the remotely locate computer where the automated measuring process is shown.

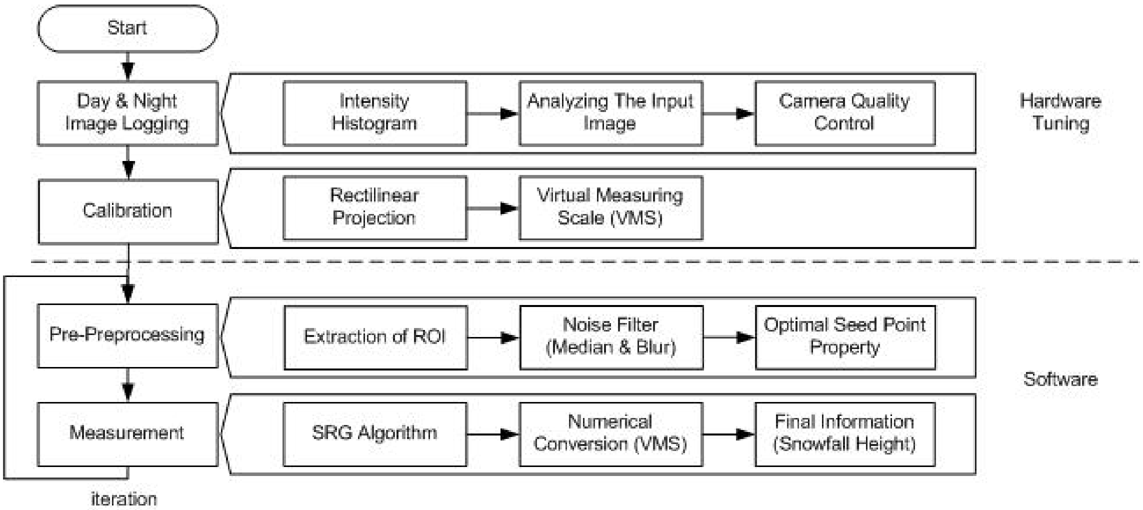


Fig. VI Flow chart of the automated snow-depth measuring process.

ruler and the camera system are installed.

As shown in the figure, the very first process is to get an optimal image from the CCD camera with instrumental conditionings; white balancing, brightness control, infrared mode, and so on. The image taking process by camera can be adjusted remotely by users, so all the other processes shown in the figure can be. After the image is obtained, the VMS (virtual measuring scale) is established based on the calibration results of the distorted images obtained by the CCD camera.

As it is not necessary to process all pixels of the acquired image, a region of interest (ROI) is extracted from the obtained image. Only the selected ROI goes through remaining image and is logged in the memory.

The ROI is then filtered to remove the noise in the image and enhance contrast at the boundary of the seed region. The median filters are used for its excellent noise-reduction capabilities and effectiveness for the impulse noise. Also the typical blurring method is applied to dilate the image and remove some remaining noises. The image obtained after these pre-processes is fed into the SRG algorithm, which starts from an optimal seed point determined by analyzing the input image characteristics.

After the SRG process and boundary searching process, the pixel information of the boundary is compared to the VMS and the pixel information is converted into a numerical value representing the actual snow-depth.

Parameters required in the processes illustrated in Fig. V are experimentally trained and optimized for various weather and lighting conditions.

IV. EXPERIMENTAL RESULTS

The performance of Cliview-High has been experimentally tested in various environments. This paper, however, shows only a set of typical experimental results where the system has been installed at a mountainous area in Gangwon Province, Korea where the frequent and sudden heavy snow-fall causes problems almost annually.

In a certain 10-day period during winter, 2005, the depth of piled snow has been measured automatically for day time and night time by Cliview-High. The automated measurements are then compared to the conventional eye-measurements which are performed locally by a well trained expert. Table I and II show typical results obtained from the experiments. The measurement using Cliview-High has been done for various snowfall conditions and lighting conditions.

Measurements are obtained for 10 different levels of snow depths at night time and 7 different levels at day time. The minimum depth tested is 0.1 cm and the maximum is 46 cm.

TABLE I THE MEASUREMENT AT NIGHT.

Snow-Cover Measurement		Difference (cm)
By real measurement	By automated measurement	
0	0.1	0.1
0.5	0.5	0
1.3	1.4	0.1
2.5	2.5	0
6.8	6.7	0.1
9.6	9.6	0
13.7	13.5	0.2
22	22.1	0.1
35	34.9	0.1
46	46	0
Average Error		0.07

TABLE II THE MEASUREMENTS AT DAYLIGHT.

Snow-Cover Measurement		Difference (cm)
By real measurement	By automated measurement	
1.2	1.3	0.1
3.1	3.2	0.1
9.5	9.7	0.2
17.2	17.2	0
22.8	22.7	0.1
35.8	35.7	0.1
43.8	43.6	0.2
Average Error		0.11

The difference between the measurements obtained by two different approaches is limited under 0.11cm, which is considered to be much smaller than the acceptable error in usual snow-depth measuring practices. The average difference between the two approaches is calculated to 0.07 cm for night time and 0.11cm for day time. The different performance between night time and day time is caused by the intensity radiation.

Also the real-time image transferring capability of the system has been tested and proved to be robust regardless of conditions.

V. CONCLUSIONS

In this paper we have developed an internet-based visual snow-cover monitoring and measuring system, Cliview-High. Cliview-High can capture the image of snow-cover against the reference marker installed in the region of our interest and transfer the image to the users remotely located through internet.

The image captured by a CCD camera is processed to correct the barrel distortion and represents the actual geometric conditions accurately. An expansive correction curve function has been applied to correct the source image and generate rectilinear projection of the actual geometric condition in the corrected image. Then the virtual measuring scale (VMS) is established on the corrected image to represent the actual geometric distance between the pixels. Based on the corrected image and the VMS, the depth of snow cover can be measured either manually or automatically. For the automated measurement of the snow depth, Cliview-High applies the fixed SRG approach to locate the surface or the boundary of the snow-pile against the reference marker or the VMS.

The effectiveness of Cliview-High has been experimentally proved in various conditions. The typical difference between the automated measurements by Cliview-High and measurements made locally by well-trained expert is limited under 0.11cm, which is considered to be much smaller than the magnitude of the error usually accepted in the current snow measuring practices.

REFERENCES

[1] S.H.Lim, G.H.Kim, S.G.Lee, S.Rhim, “Internet-Based Visual Snow-Cover Monitoring and Measuring System”, SICE-ICASE International Joint Conference, 2006, pp. 3887-3890.
[2] Labine, C., “Automatic Monitoring of Snow Depth,” *Proc. of the Int. Snow Science Workshop, Banff, Canada*, pp. 179.
[3] Chang, A., et. al. “Estimation of snow depth from AMSR-E in the GAME/CEOP Siberia experiment region,” *Proc. of IEEE IGARSS*, 2004, pp.3670-3673.
[4] Jinsong Wang, Nilesh Patel, William Grosky, “Video Data Management Using a Seeded Region Growing Technique”, *Proc. of the IEEE ISMSE*, 2004, pp. 561-564.
[5] R. Adams, L. Bischof, “Seeded Region Growing,” IEEE Transactions on pattern analysis and machine intelligence, vol.16, no.6, 1994, pp.641-647.
[6] Rafael C. Gonzalez, Richard E. Woods, “Digital Image Processing (Second Edition),” *Prentice Hall*, 2002.