Scene Understanding and its Application to Cloud Imaging

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With the existence of ubiquitous cameras around us, there has been a paradigm shift in understanding and analyzing a scene. The central theme of this thesis is to use conventional cameras to capture images of a scene and derive essential information about the surroundings. In this thesis, we focus our attention on images captured by ground-based sky cameras, which are essential for several remote sensing applications.

Ground-based sky cameras, popularly known as Whole Sky Imagers (WSIs) are now extensively used by remote sensing analysts. They are useful in variety of applications: cloud attenuation analysis, local weather prediction and solar and renewable energy forecasting. They complement conventional weather satellite images with higher temporal and spatial resolutions. The WSIs captures images of the earth's atmosphere in regular intervals of time, and stores them in their local archive. In this thesis, we analyze this huge amount of captured image data, and proposed several algorithms and methodologies for a wide variety of applications.

Firstly, in this thesis, we design efficient, low-cost, and highly flexible ground-based sky cameras. Our custom-built WSIs are called WAHRSIS, which stands for Wide Angle High Resolution Sky Imaging System. These imagers are equipped with high resolution fish-eye lens that captures the images of the sky scene at user defined intervals of time. Our imagers have a lower cost, higher flexibility and higher image resolution as compared to the commercial imagers.

Secondly, we propose an efficient cloud segmentation algorithm that surpasses the performances of the current state-of-the-art algorithms. The segmentation of a cloud mass from a sky/cloud image is essential for automatic computation of cloud coverage. In this thesis, we present a supervised segmentation framework for ground-based sky/cloud images based on a systematic analysis of different color spaces and components, using partial least squares (PLS) regression. Unlike other state-of-the-art methods, our proposed approach is entirely learning-based and does not require any manually defined parameters. We release the Singapore Whole Sky IMaging SEGmentation Database (SWIMSEG), a large database of annotated sky/cloud images, to the research community. In addition to this PLS regression approach, we also explore the use of High Dynamic Range (HDR) imaging for solving the cloud segmentation problem.

Thirdly, in addition to cloud coverage computation, we also propose a framework for automatic cloud type recognition. We present a texton-based classification approach that classifies sky/cloud image patches efficiently into 5 types: clear sky, patterned clouds, thick dark clouds, thick white clouds and veil clouds. Our proposed algorithm has the best performance as compared to conventional cloud-type recognition algorithms. We also release a large-scale cloud categories database called Singapore Whole Sky IMaging CATegories Database (SWIMCAT) for further benchmarking purposes.

Fourthly, we also use these ground-based sky cameras in a stereo-setup for accurate reconstruction of cloud profile. In this thesis, we provide a theoretical analysis on point-localization of multi-camera setups for finite-resolution camera settings. In our work, we propose a consistent and optimal point localization algorithm for noisy camera poses and error-free matching between image frames. We formulate this point localization task as a gradient-ascent optimization function. The constraints used in maximizing the objective function are derived from computational geometric settings of the camera setup. Experimental results verify the efficacy of our approach as compared to the current state-of-the-art localization algorithms.

Finally, we use the captured sky/cloud images obtained from sky cameras to estimate other meteorological sensor data. In this thesis, we use our WAHRSIS images to propose a solar radiation estimation model. Our proposed methodology can accurately capture the short-term rapid fluctuations of solar irradiance. Unlike solar pyranometers, ground-based sky images have additional information about cloud coverage and cloud movement. This greatly helps in solar energy forecasting.