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Annual Technical Progress Report (End Year 2)

Aurora Phenomenon Localization, Classification, and Temporal Evolution Tracking

Timothy S. Newman, PI (G. Germany, C. Hung, and J. Spann, Co-Is[1])

Department of Computer Science

University of Alabama in Huntsville

1 Introduction

This report is a summary of the progress for the first 24 months of effort on the AISR award NNG-06-GE60G. The project officially began on March 15, 2006.

1.1 Problem Background

Our work aims to produce an improved on-line tool for retrieval of images of interest in the large archives of images produced by the NASA Polar mission's UVI sensor and the IMAGE mission's FUV sensor. There are approximately 10 million images in these collections, and it is challenging for researchers to find all auroral images of interest for investigations.

Previously, Co-I Germany developed the On-line Search Tool (OST), an interface to part of the archive of UVI images. The tool allows retrieval of UVI images acquired before 2005 based on sensor characteristics—such as time of acquisition, sensor location, field of view, etc.—and three simple image features—auroral power, presence of a full auroral oval, and presence of a clear oval. The three simple image features were determined using automated image processing and analysis operations (i.e., via what could be considered rudimentary image mining). While OST was a great advance, it is limited in that it can retrieve based only on sensor characteristics and a few simple image features. It is also limited in that its image feature-based retrieval follows a scheme that is not tolerant of certain commonly-occuring image properties, such as high levels of noise, low contrast, and stars in some images; these properties sometimes confound the image feature identifier. Presence of day glow in many images can also confuse the methods used by the tool's image feature identifier. There is no existing tool that allows retrieval of FUV images based on simple auroral features.

The project aims to improve the robustness of the existing OST to image complications and to extend the OST capabilities to allow FUV image retrieval. In particular, one aim is to develop more robust methods to locate the auroral oval in either type of imagery, primarily by exploiting the known shape of the auroral oval. Given a localization of the auroral oval, characteristics of the aurora in each image are more likely to be determined, allowing retrieval of imagery based on aurora characteristics. A second aim is to support retrieval of images based on temporal or on temporally-related/detectable features, for example, retrieval of images of theta aurorae or during substorm onset.

[1] Dr. Germany is with the University of Alabama in Huntsville, Dr. Hung is with the Southern Polytechnic State University, and Dr. Spann is with the NASA Marshall Space Flight Center.

2 Brief Progress Summary (Results to Date)

In this section, the progress on the project is briefly summarized. Many low-level details have been omitted; our aim is to provide a fairly high-level summary of progress.

To date, the major accomplishments include: (1) achieving an improved shape-based mechanism for more reliable localization of the auroral oval in UVI imagery; (2) extending this mechanism to auroral oval detection in FUV imagery; (3) creation of a suite of methods for detecting theta auroras, auroras with trans-polar activity, standard auroras, and "thick" auroras in UVI imagery; and (4) development of a method for improving the accuracy in auroral oval identification and shape estimation in UVI imagery. In addition, spin-offs from the work have resulted, including creation of a mechanism for very fast ellipse detection in any sort of imagery, and creation of a mechanism for fast ellipsoid detection in range or scattered point data. During Year Two, manuscripts describing those methods were written. One was submitted for publication. The other will be submitted soon. Some effort has also been expended toward developing substorm detection mechanisms, including exploration of shape-based approaches and approaches based on decision trees applied to features extracted from wavelet-transformed image sequences. We do not discuss the substorm item in detail here since it remains a work in progress.

2.1 Oval Detection in UVI

The first major accomplishment in our work was creation of a shape-based processing methodology that allows automated localization (detection) of the auroral oval in UVI imagery. The method exploits the fact that the auroral oval's shape in satellite imagery is elliptic. The foundation of this method was established in our pilot AISR project. (The prior work was reported in [4], and technical details of its basis were reported in [5].) The method was refined in the early months of this project. (We determined that an alternative early processing step could improve the method.) In the past year, we have conducted extensive testing of the improved method. The testing involved over 3000 images collected between 1997 and 2003. For these images, the goodness of the localization versus a localization by the next best automated method (the so-called AMET method of Li et al.) was assessed by a human observer. In over 56% of the images, the new method was judged to be superior to the AMET method. When more than 80% of the auroral oval was viewable in the image, the new method was best about 95% of the time, however. Since we observed the new method to actually be worse than the AMET method when less than 80% of the auroral oval is present, we further improved our auroral oval detection mechanism for UVI imagery to employ the new method when the field of view contained much of the region that normally contains the auroral oval and to employ AMET in other cases.

A manuscript describing the auroral oval detection method was written and submitted to a journal during Year Two. It is currently undergoing revision for resubmission. In addition, the method formed the centerpiece of a Ph.D. dissertation [1] that was defended in the summer of 2007. During Year Two, the SPSU sub-team also investigated if combining rough set theory and k-means segmentation could produce a reasonable localization of the aurora. This avenue of investigation will not be pursued further due to time limitations.

Some of our work in recent months has focused on incorporating the hybrid mechanism into a mirror (beta) site of the UVI OST. During Year Two, this mirror site was created and tested. (The site seems to be functioning fine.) This site will be where the new tool for UVI and FUV imagery manipulation is built and tested, avoiding interference with the existing OST.

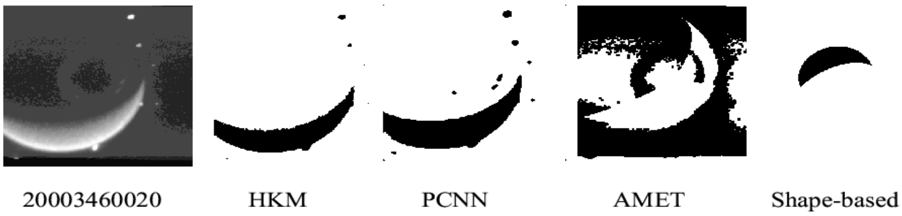


Figure 1: Comparison of Auroral Oval Detection Methods for FUV

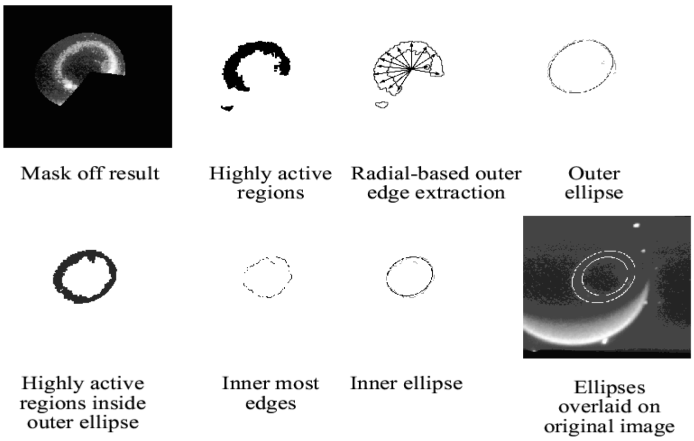
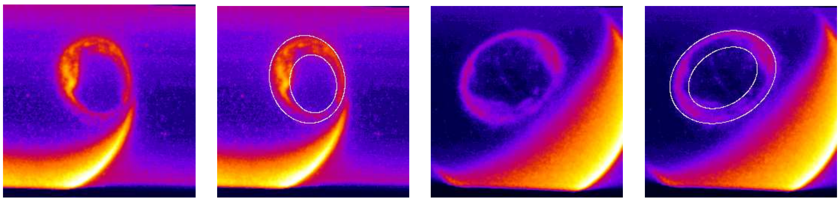


Figure 2: Shape-Based Method for Auroral Oval Detection in FUV Images

2.2 Extending Oval Detection Method to FUV

Another major accomplishment to date has been the development of a methodology for automatically locating the complete auroral arc in FUV imagery. As suggested earlier, the approach is shape-based. It is an extension of the method used to detect the auroral oval in UVI imagery. Key adaptations were necessary to allow shape-based processing to be successful for FUV image feature retrieval since the approach followed for UVI usually fails when applied to FUV, as shown in Figure 1 for one FUV image. (The original FUV image is shown on the left side of the figure and the shape-based processing's result is shown (as a black crescent) on the right side of the figure.) The other existing UVI auroral oval detection methods also fail, as shown in the same figure. The reason for the failure of all the methods is the very large, bright region of dayglow in most FUV images, including the one shown in Figure 1. (The dayglow is the large crescent near the bottom of the image.) Most of the methods mistook the dayglow for the auroral oval.

The method's basic processing scheme is shown in Figure 2. The major change that was made to



(a) (b) (c) (d)

Figure 3: (a) Original FUV Image A; (b) Localization overlaid on image; (c) Original FUV Image B; (d) Localization overlaid on image

the shape-based processing to allow application to FUV was to first remove the portions of the image associated with the magnetic local times (MLTs) where dayglow could occur. Then, the outer oval was found using the remaining parts of the image. Another change involved finding the inner oval boundary after restoring to the image all regions inside the outer oval. Such processing allowed the dayglow effects to be overcome in a way that allowed reasonably accurate detection of the auroral oval's extents.

The auroral oval detection method for FUV was tested on 131 images from five days of the year 2000. In 123 of the tested images, the method's results were judged to accurately match the results produced by human experts. In the other images, results were subpar but still were not too unreasonable. Two example FUV images and the overlay of the automated technique's auroral oval localizations are shown in Figure 3.

The new approach is described in work that was published in May 2007 [3]. To our knowledge, that work is the first reported effort for auroral oval detection in FUV.

2.3 Detecting Thetas and Other Special Cases in UVI

The third accomplishment is that we completed creation of methods, begun in a prior AISRP project, that allow detection of theta auroras, auroras with trans-polar activity, standard aurora, and auroras that are "wide" in UVI imagery. The methodologies were presented in a paper in October 2006 [2].

An outline of the processing steps for detecting thetas is illustrated in Figure 4 for a UVI image from 1999. The main idea is to first find and remove the parts of the image associated with the auroral oval itself, leaving only trans-polar structures. Then, the degree of linearity of the trans-polar structures is determined. Highly linear structures are taken to be theta auroras. (If the structures are not highly linear, the case is taken to be an aurora with trans-polar activity.) The whole processing is driven by the shape-based method's identification of the auroral oval; processing for theta detection is limited to the region inside the auroral oval. Shape-based processing also allows detection of the thetas and non-thetas.

Standard auroras were taken as those with no appreciable trans-polar activity. Wide auroras were taken as those whose widest distance between the inner and outer auroral oval boundaries was more than 1500 km.

We have conducted a benchmark experiment to estimate the performance of the methods for classifying auroras as theta, standard, and wide aurora types. The precision of the methods averaged about 85% and the recall averaged about 80%. The full experimental results were reported in the October 2006 paper [2].

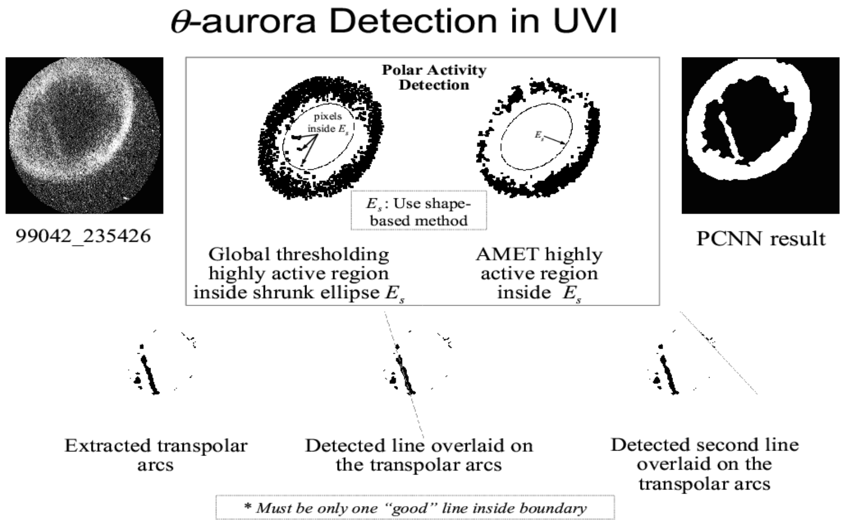


Figure 4: Theta Detection

In upcoming months, the methods will be incorporated into the UVI archive feature miners. Later in the project, they will be adapted for use with FUV and incorporated into FUV feature miners.

2.4 Improving Oval Identification Accuracy

Although our shape-based method for extracting the auroral oval in UVI imagery has been demonstrated to be superior to the existing methods, it nevertheless does not produce a perfect result. Recently, we have developed a new mechanism that can improve its performance. This mechanism, in fact, has broader applicability in that it can improve ellipse detection in other cases that utilize the same core methodology that we use. That core methodology is the randomized Hough Transform (RHT). The RHT, while producing results in a reasonable amount of time and with good accuracy, can yield sub-par results if the object in the image has a somewhat noisy boundary. Specifically, RHT-based methods can estimate that the shape of an elliptical object in an image can be slightly bigger or smaller than the actual shape. The position or orientation of the object can also be estimated to be slightly displaced from its actual position or orientation.

One way to improve the robustness of RHT-based methods is to consider the distinctiveness of the recovered parameters. We have developed a new mechanism [7] for measuring elliptic parameter distinctiveness which is applicable to RHT-based ellipse recovery. Our work was motivated by recent work in the literature [6].

The crux of the mechanism is to examine a family of curves that are similar to the one that the initial processing identified. The new measure that we developed to accomplish this end provides better results than does the other recent mechanism [7], at least for application to auroral imagery.

Figure 5 illustrates the improvement from the new mechanism. The figure shows one UVI image in part (a) and a manual identification of the auroral boundary in part (b). In part (c), the manually traced boundary is shown in red and the fitted boundary from use of our basic RHT-based processing

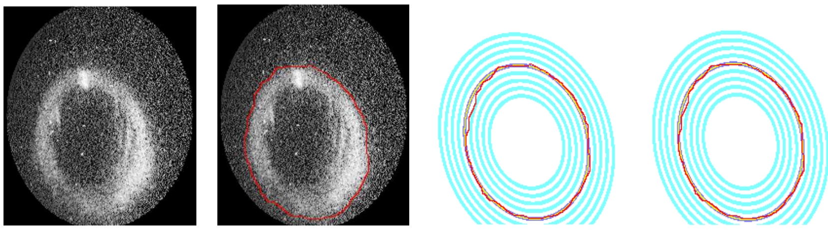


Figure 5: (a) Original image; (b) Manually traced outer boundary; (c) Old Method (green) vs. Manually traced (red) boundary; (d) New Method (green) vs. Manually traced (red) boundary

is overlaid in green. In part (d), the manually traced boundary is shown in red and the fitted boundary from use of the RHT-based processing coupled with our new curve distinctiveness mechanism is shown in green. In parts (c) and (d), the family of curves that were checked are also shown (in blue). The result shown in the figure illustrates that the curve distinctiveness measure can allow modest improvements in auroral oval localization.

3 Plans for Next Year

One key issue to be addressed in the next year is incorporation of all of the methods into a production version of UVI OST. That task involves re-populating a database of image features using automated image miners. That task should complete during the summer of 2008.

Another major task is creation of image miners for the FUV imagery that are based on our FUV localization methods. Those miners will then be utilized in a new version of the OST that supports FUV. We will need to develop a new user interface for the FUV imagery and do a lot of testing as the FUV methodologies we've developed are not as mature as our UVI processing methodologies.

Another major issue is the testing of the final UVI-FUV OST web site/software. That will take place at the end of Year Three of the project.

Lastly, work on substorm detection and tracking will also continue.

Hopefully, several papers related to the work will be accepted during Year Three as well.

4 Contributions to Education

We also would like to note some educational outcomes arising out of the report. One Ph.D. dissertation [1] was produced by a student, Chunguang “Ken” Cao, supported by the project. Dr. Cao has been first author of many papers [2, 3, 4, 5] resulting from his work on the project. A second Ph.D. student supported for a few months of the project has also produced one publication as a result [7].

5 Conclusion

Three major initiatives have seen good progress in the first two years of the project, as identified in the report. Our project is a little behind target for where it should be at the end of the second year, largely due to the graduation of one major worker on the project (Dr. Cao) and the ramp-up time for his replacements. We will try to make up the lost time during the first few months of Year Three.

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