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Developing Automated Detection, Tracking and Analysis Methods for Solar Activities via Machine Learning

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Solar active regions (ARs) are the patchy volumes in the solar atmosphere with strong magnetic fields, where various activities occur, including flares and filaments (prominences). Studying the evolution and morphological features of ARs and solar activities is significant for understanding the physical mechanisms of solar eruptions and beneficial for forecasting hazardous space weather.[1]

However, the increasing time cadence and spatial resolution of observations generate large amounts of data, making manual inspection difficult. Automated detection is an efficient method for deriving features of solar activities from observations for further analysis. To address this challenge, we have developed automated detection, tracking, and analysis methods for filaments, flares, and ARs using machine learning techniques.

Specifically, we developed an automated DBSCAN-based solar active regions detection (DSARD) method[2] for solar active regions observed in magnetograms. This method is mainly based on an unsupervised machine learning algorithm called density-based spatial clustering of applications with noise (DBSCAN). Based on the U-Net[3] semantic segmentation model, we developed an automated detection method for prominences and ARs above the solar limb on 304 Å filtergrams. We also use the U-Net model to identify filaments and implement the Channel and Spatial Reliability Tracking (CSRT) algorithm for automated filament tracking.[4] Recently, we improved the automated detection and tracking workflow by implementing a multiscale feature extraction segmentation model called Compound U-Net.[6] Besides the filaments, this method can be applied for solar flares and other brightening features in Hα and UV observations.

Further analysis is needed once solar activity has been detected. Inverse methods have been developed for this purpose. We use a cloud model to invert the line-of-sight velocity of filaments and employ a graph theory algorithm to extract the filament spine, which advances our understanding of filament dynamics.[5] We construct FCNN models[7] that can quickly and accurately invert solar chromospheric parameters (e.g., particle number density, temperature, and plasma velocity) using Hα spectral data based on the Radiative Hydrodynamics Code (RADYN)[8]. We present a novel physics-reinforced generative adversarial network (PRO-GAN)[9], an integrated deep learning framework designed to efficiently transform solar potential fields into corresponding NLFFFs while enforcing physical constraints to improve the results.

The efficiency and accuracy of these methods have been validated through rigorous testing. Their application to recent solar cycles has yielded statistically significant results that are consistent with those of previous studies, demonstrating the reliability and validity of our methods.

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