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Automatic detection of Jupiter's White Ovals in Juno-JIRAM imagery using a computational model of human vision – preliminary results

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Abstract

White Ovals are Jupiter's anticyclones staggered with cyclones according to a stable spatial configuration known as "Karman vortex street", which looks very bright at visible wavelengths and extremely dark in the thermal portion of the electromagnetic spectrum. Their accurate characterization was accomplished according to [1] by means of a multiple scattering radiative transfer approach starting from 5 microns JIRAM images. The application of a Computer Vision (CV) algorithm to JIRAM multi-spectral imagery acquired during the first Juno perijove allowed the automatic identification and qualitative characterization of the white ovals discriminating between cyclones and anticyclones.

1. Introduction

In a feature engineering phase constrained by *a priori* physical knowledge of the Jupiter atmosphere, nine wavelength channels were selected from the Juno-JIRAM multi-spectral imagery acquired during the Juno's first perijove as those most sensitive to changes in physical variables expected to characterize White Ovals, including cloud densities, cloud altitudes, ammonia concentration, atmospheric temperature, etc. For visualization purposes, the selected nine channels were depicted as three false-color monitor-typical RGB images (Fig. 1) showing sensory data correlated with, respectively, cloud densities, cloud altitudes and temperature-driven phenomena. In each selected RGB image, the Jupiter White Ovals are clearly visible by human photointerpretation, based on an unequivocal combination of colorimetric and spatial image-object properties, such as shape and size, together with inter-object spatial topological and spatial non-topological relationships.

To mimic the capacity of human vision in detecting White Ovals across each of the three selected RGB images, a computational model of human vision was designed and implemented as an automated computer vision (CV) algorithm, requiring no human-machine interaction to run. Synonym for scene-from-image reconstruction and understanding, vision is an inherently ill-posed cognitive (*information-as-data-interpretation*) task. Encompassing both biological vision and CV, vision is *part-of* the multi-disciplinary domain of cognitive science, ranging from philosophy to linguistics, neuroscience, computer science, statistics, etc., where the CV discipline is *subset-of* Artificial General Intelligence (AGI). Vision is inherently ill-posed because affected by, first, a data dimensionality reduction problem from the 4D scene-domain to the 2D image-domain and, second, by a semantic information gap, from the sub-symbolic image-domain to the symbolic scene-domain. Since it is inherently ill-conditioned, vision requires *a priori* knowledge in addition to sensory data to become better posed for numerical solution. A second unquestionable true-fact is that, in vision, spatial information typically dominates color information. For example, human panchromatic and chromatic visions are nearly as effective.

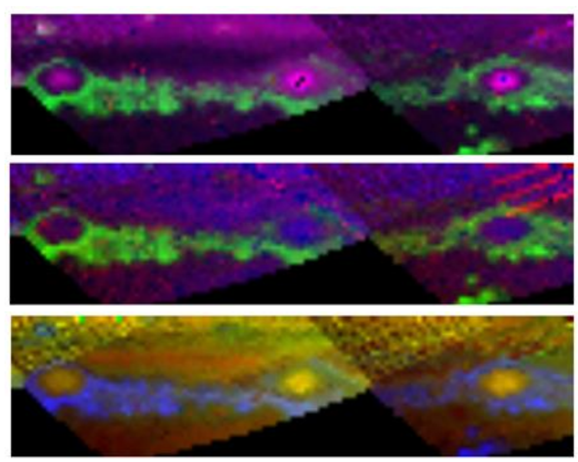

Figure 1: From top to bottom, the three false-color monitor-typical RGB images, identified as RGB1 to RGB3 respectively.

2. Computer Vision system design and implementation

The proposed CV system design (architecture) consists of (see Figure 2): (1) an original self-organizing (adaptive-to-data) color constancy first stage, capable of enhancing color brightness and color contrast automatically; (2) inspired by linguistics, an *a priori* knowledge-based (deductive) inference system (expert system), called RGB image automatic mapper (RGBIAM), for automatic color naming of vector data in an RGB color space; (3) a well-posed (deterministic) two-pass connected-component multi-level image labeling third stage, where image-objects (segments) are automatically detected as connected sets of pixels featuring the same color name; (4) fourth-stage parameterization of image-object shape properties, by means of an original minimally dependent and maximally informative (mDMI) set of scale-invariant geometric indexes; (5) generation of a segment description table, capable of entity-relationship modeling, where both colorimetric and spatial information components are coped with; (6) a hybrid (combined deductive/ top-down/ learning-by-rule and inductive/ bottom-up/ learning-from-data) image-object classification stage, based on a convergence-of-evidence approach to CV, capable of spatial reasoning.

To mimic human vision in detecting White Ovals in the three selected RGB images based on converging color and shape evidence, the proposed CV system was instantiated as follows. (A) (Numeric) RGB data were submitted to color constancy and mapped by RGBIAM onto (categorical) color names. (B) Image-object shape indexes were estimated and discretized into fuzzy sets (low, medium and high). (C) Discrete and finite sets of target-specific color names and geometric fuzzy sets were logically combined by a target-specific CV decision-tree classifier.

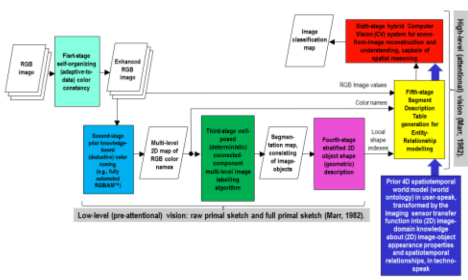

Figure 2: The proposed CV system workflow.

3. Application to Jupiter's White Ovals

First, the RGB1 (number densities) image was input to the CV system to select candidate areas for the three ovals, clearly visible in the top row of Figure 1, on the basis of a single color label (25) out-of-50 RGBIAM color names. Second, candidate areas for the three ovals were refined by removing from the previous mask all image-objects detected by the CV system in the RGB3 (temperature) image, see bottom row in Figure 1, whose color name is different from label 21 or 22 out-of-50 and whose shape roundness $R \in [0.0, 1.0]$ is "not fuzzy high", e.g. < 0.66. Here R is defined as a scale-invariant shape roundness [2]: $R \in [0.0, 1.0] = 4*\text{sqrt}(A)/PL$, where A is the area (number of pixels) of the image-object and PL is the 4-adjacency cross-aura measure estimated from the total (inner and outer) perimeter of the image-object. To accomplish cyclone and anticyclone differentiation found by [1] with an independent Bayesian approach, color label 2 or 25 out-of-50 were selected from the RGB2 (heights) image, see mid row in Figure 1, and combined with a logical AND operator to the aforementioned mask generated from images RGB1 and RGB3.

4. Conclusions and future works

An automated (parameter-free) hybrid (combined deductive and inductive) CV system for Jupiter's cyclone and anticyclone detection and discrimination, although applied preliminarily to a single data set, scored "high" in terms of outcome and process quantitative quality indexes, such as degree of automation, accuracy, efficiency and scalability. For example, in terms of scalability, the proposed CV algorithm allows to stratify an image into layers (masks, candidate areas) where to apply Bayesian (class-conditional, masked, driven-by-prior-knowledge) quantitative analysis, such as masked atmospheric feature estimation. Stratified image analysis typically diminishes computation time in comparison with driven-without-knowledge image analysis approaches, where a whole image is treated the same by a driven-without-knowledge local operator. As a future development, the CV system robustness (variance) to changes in input data will be assessed upon multiple Juno-JIRAM data acquisitions, structured according to the proposed RGB image triplets.

References

[1] Sindoni et al., 2017, https://doi.org/10.1002/2017GL072940.

[2] Baraldi and Soares, 2017, https://arxiv.org/abs/1701.01941.