Image Processing in Astronomical and Geospatial Imagery

Riley C. Payung

Computational and Data Sciences, George Mason University

ENGH 302

Dr. Miscavige

July 3, 2020

Abstract

This literature review deals with the applications of image processing in Astronomical and Geospatial images, following the methodology of each of the sources mentioned in this paper. This paper is meant to show the current progress as well as applications of machine learning and image processing in the astronomical and geospatial fields, both of which have major implications in computational and data sciences. Image processing is used for a multitude of machine learning applications, including artificial intelligence, object detection, and natural language processing. The methods involved in this literature review all include the use of calculus-based methods, including the gaussian-gradient method, max-tree method, and maximum entropy. An understanding of both calculus and statistics is helpful, but not needed. This literature review will look at the methods in-depth and the efficiency of the algorithms, looking for the most efficient algorithm or if there is a need for an entirely new algorithm altogether.

Introduction

Applications of image processing have been around for a long time, and even with early image processing techniques, the outcome has remained the same: How can images be processed to show patterns or symbols, including text, ancient calligraphy, planets, road networks, etc.? Over the last forty years, techniques for image processing have improved with the ever-increasing computational power of computer components. This does not come as a surprise, since the techniques involved in image processing have improved on multiple fronts, mainly speed. Moore's Law, which states that computing power doubles while the cost of computing halves every two years, has been very accurate, even in modern times. This literature review will cover and analyze the techniques used over the previous forty years, their applications, fears, as well as the probable future of image processing.

Methods of Image Processing

Due to the increase in computing power, the techniques for image processing have sped up since the late 1970’s, where early studies on image processing were done by the National Aeronautics and Space Administration at the California Institute of Technology by Jean Lorre. Mr. Lorre transposed an image of alphabetical letters over astronomical imagery, blurred the image, and then attempted to restore the alphabetical characters using computing. With some success, the image was nearly restored to the original using the maximum entropy restoration and chi-squared residuals methods with some minor blurring (Lorre, 1979). Despite the image being blurred into near nothingness, it was quite the remarkable feat. These methods involve using both Wiener deconvolution and a degrading matrix filter in order to deblur the image. Wiener deconvolution does not fully deblur an image, leaving some trace blurring in the image, which is why Mr.Lorre also uses a degrading matrix. It is worth noting that Mr. Lorre experimented with multiple different variables in order to achieve varying results. The image ended up being restored the best with a ratio of fifteen and a five-by-five degrading matrix.

Despite the near completeness of the image using those variables, using a smaller ratio and larger matrix produces slightly similar results to the latter on a target that could be considered noiseless, meaning it has no discolored pixels in the background; however, doing the same on a noisy target will not produce great results. Technological advancements in computing and techniques used for image processing have built on this study, allowing for further sharpening of images, better detectability, and better processing results. Recently, the Gaussian method has been used to detect objects, making it part of the most modern of techniques used.

The gaussian method, also called normals mapping, is dependent on an understanding of vector calculus and statistical analysis. “Preliminary analysis in astronomical image processing includes understanding the dimensional properties or the shape index profile of the celestial object in the image. Interpreting the shape index [11], orientation index and dimensional profile of the object helps astronomers to correctly identify the class it belongs to and also to conduct subsequent research on it… This provides a clear intuition of the illumination concentration in the image, spatial orientation of the celestial object and also helps in defining the shape index of that object making it a crucial step in astronomical image analysis.” (Diganta, 2018). The gaussian method is used to create a mapping of the orientation of an object, aiding in the understanding of the three-dimensional space transposed over a two-dimensional image.

In addition to the Gaussian method, using Gradients aids in showing any patterns in the image. “Image Gradients computation is also used as a process for feature extraction and texture matching or pattern recognition within the image.” (Diganta, 2018). Using both techniques gives a rough, but fundamental understanding of any object’s orientation and patterns that may not be nakedly visible to the human eye. This is achieved with color or gradient intensity, associating certain colors within the image with each other.

Mr. Moschini presented similar findings and results using the same techniques in chapters three and four of his doctoral thesis, presented in May of 2016. “In our method, background pixel values are assumed to be from a Gaussian distribution… The background is approximated by the mean value of flat tiles and is subtracted from the image.” (Moschini, 2016). Moschini uses the Gaussian method to remove the background, since it is considerably the same intensity or color, allowing for both the detection of objects within an image as well as the orientation. Larger clusters in the images will be more normalized, following the Gaussian distribution, and aids detection of even smaller objects.

Furthering our understanding of image processing techniques, the max-tree method gives us a hierarchical approach to image processing. “Every node in the tree corresponds to a peak component, which is a connected component at a given intensity level in the image” (Moschini, 2016). A hierarchical approach to a Gaussian or even Poisson distribution can be represented as a tree where an image is partitioned allowing for binary detection of objects and builds on our previous gaussian method used by both Mr. Moschini and Mr. Diganta in *Advanced Image Processing for Astronomical Images*. Partitioned tiles of an image are averaged by their intensity level to create a hierarchical max-tree and detect possible objects within an image. “Attribute filters compute some property or attribute, like area or shape measures (circularity, center of mass, ...) for every connected component.” (Moschini, 2016). Moschini goes on to show that the use of a max-tree structure makes detection using the Gaussian method much quicker. Out of the methods mentioned in this literature review, this is by far the fastest because of the nature of the max-tree structure. A max-tree can go by different names, mainly the term ‘min-max heap,’ which has many uses in the complexities of computer science and machine learning.

Into the object detection uses of the max-tree method, Moschini states “We noticed that MTObjects detects more objects nested in larger objects (galaxies), when the pixel values of the nested objects are above the SExtractor’s threshold.” (Moschini, 2016). The MTObjects is an abbreviation for Max-Tree Objects and SExtractor thresholds are the number of pixels of a certain color that are found before the object is classified as something different from the overall image. The max-tree structure allows for both quicker and more accurate detection of objects within the image in question, meaning that inside of a galaxy, it is possible to detect stars or black holes. This paired with the detection of the galaxy itself shows us that the max-tree method is the strongest and most efficient method of those mentioned in this literature review at detecting objects in images.

Efficiency of Methods

Relative efficiency of these methods has improved over time; however, there is still a bottleneck in the execution time since there is variability based on which computer system is used. All of the methods mentioned in this review are software based. “With advances in the VLSI (Very Large Scale Integrated) technology hardware implementation has become an attractive alternative. Implementing complex computation tasks on hardware and by exploiting parallelism and pipelining in algorithms yield significant reduction in execution times.” (Rao, 2006). With the advent of technological advancements in computer hardware and the understanding of Moore’s law, it may be possible in the future that we may see more computer chips that are dedicated to just a single task, acting as their own specific processor. For example, artificial intelligence chips which would only handle tasks related to the randomization or computation of solely artificial intelligence could be one of these chips.

In 2006, the total number of transistors in a computing chip was one billion according to Ms. Zyga at Phys.org in an article published in February 2008 on Intel’s Microchips while In 2019, AMD’s EPYC processor boasted an astonishing 39.5 billion transistors (Allan, 2019). It is very clear to see that Moore’s Law still holds true and will for the foreseeable future. The point of this information is to show that the technological advancements of hardware has made the methods used in this review more viable; however, even with the advancements, the algorithms are only sped up, and further research may need to be done to see whether these advancements could better benefit astronomy and geospatial analysts with the invention of a newer algorithm that will change the process completely, like how the Gaussian method did when it replaced Mr. Lorre’s method of maximum entropy. Further advancements will ultimately make the application of image processing in geospatial and astronomical imagery more viable.

Applications of Image Processing

With the major implications that these techniques have on astronomical imagery, it should be unsurprising that that is not their only use. The field of geospatial analytics allow us to look at the surfaces of planets, mainly our own, in order to find patterns and detect objects. Geospatial visual analytics takes an image from satellite and detects objects within that image; this is how road mapping works on apps like Apple Maps and Google Maps. “Physical Objects like roads, buildings or rescue teams are involved in the processes.” (Amicis, 2009). These methods are widely used to detect things like fires, motion, and many other applications. Image processing’s uses have greatly improved analyst work, but some have expressed fear over the use of these methods in the workplace, and how they may replace human analysts in the future.

Even though image processing techniques, and less specifically machine learning, have been around for decades, employees at the National Geospatial-Intelligence Agency (NGA) are not convinced that these methods will cause unemployment after being implemented in the workforce. “At the time, Cardillo said the NGA workforce was “skeptical,” if not “cynical” or “downright mad,” about the idea of computer vision technology becoming more of a presence in analysts’ work and potentially replacing them.” (Goldstein, 2018). Computer vision is just another name for machine learning techniques involving image processing. The fears that are expressed by NGA employees are certainly viable to consider; however, the idea of image processing is to aid in the discovery of anything that could be missed by analysts, otherwise known as human error, not to replace the analysts completely.

Conclusion

While the research on the topic of image processing in astronomical and geospatial imagery is still ongoing, it is clear newer methods of image processing may be warranted, and more research into said methods as well as their effects on the employment of individuals involved is still needed. Other methods may be available in the industry as a trade secret or patented technologies. The research necessary for discovering new methods could emerge from the privatization of the space industry or intelligence community. Research could also be contracted by the National Aeronautics and Space Administration (NASA) or National Geospatial Intelligence Agency (NGA) to other private companies. In either scenario, Image processing in astronomical and geospatial imagery is still a field that requires further research in order to improve upon previous iterations or present new methodology.

APA References

Allan, D. (2019, October 23). AMD Epyc CPU with 39.5 billion transistors is a jaw-dropping sight under the microscope. Retrieved June 28, 2020, from https://www.techradar.com/news/amd-epyc-cpu-with-395-billion-transistors-is-a-jaw-dropping-sight-under-the-microscope

Amicis R.D., Conti G., Piffer S., Simões B. (2009) *Geospatial Visual Analytics*. In: Amicis R.D., Stojanovic R., Conti G. (eds) GeoSpatial Visual Analytics. NATO Science for Peace and Security Series C: Environmental Security. Springer, Dordrecht. 260 – 85.

Diganta, M., Sparsha, M., & Bhargav, A. (2018, December 23). *Advanced Image Processing for Astronomical Images.*

Goldstein, P. (2018, August 01). Computer Vision: How Feds Can Use AI to Advance Beyond Image Processing. Retrieved June 24, 2020, from https://fedtechmagazine.com/article/2018/08/computer-vision-how-feds-can-use-ai-advance-beyond-image-processing-perfcon

Lorre, J. (1979). Application of digital image processing techniques to astronomical imagery, 1979. National Aeronautics and Space Administration, Jet Propulsion Laboratory, California Institute of Technology. Retrieved June 8, 2020, from https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19800011714.pdf

Moschini, U. (2016). Efficient morphological tools for astronomical image processing. [Groningen]: University of Groningen.

Rao, D. V., Patil, S., Babu, N. A., & Muthukumar, V. (2006). Implementation and evaluation of image processing algorithms on reconfigurable architecture using C-based hardware descriptive languages. *International Journal of Theoretical and Applied Computer Sciences*, *1*(1), 9-34.

Zyga, L. (2008, February 04). Intel Microchip Packs Two Billion Transistors. Retrieved June 28, 2020, from https://phys.org/news/2008-02-intel-microchip-billion-transistors.html