Morphological Operations Applied to Crack Detection in Digital Art Restoration

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Key Points

This paper will be addressing the issue of crack detection in digital art restoration using operations of mathematical morphology. Mathematical morphology is a method of image and signal processing derived from set theory. There are many possible applications of mathematical morphology (many of the papers I looked through were based around license plate scanning, for instance), but this paper will focus on its applications within the field of digital art restoration. Two of the papers I reference – [1] and [6] – examine the usage of morphological operations within the context of a specific digital art restoration project – the Ghent Altarpiece in [1], and Theran wall paintings in [6]. Two other papers – [2] and [9] – also examine the concepts of mathematical morphology as applied to digital art restoration, but in a more generalized manner – [2] looks at morphological operators when applied to digital art restoration in general, and [9] looks at the statistics of crack misidentification. Sources [4], [5], [7], and [8] are all introductory material to mathematical morphology, and [3] presents an algorithm for edge detection, which will be covered briefly in the background section of this paper.

Sources [4], [5], and [7] provide information on the functionality of morphological operators, and do not require previous understanding of set theory or morphological concepts. [8] provides similar information to that found in the previous three sources, but this information is somewhat more complex; some previous knowledge of set theory is useful, and the information obtained from this source, while useful, is best understood when taken in conjunction with the information obtained from [4], [5], and [7]. [3] is fairly mathematically complex, and requires some understanding of mathematical principles such as the convolution integral. While the information regarding edge detection drawn from [3] is useful and will likely be included in some form as background information in this paper, I hope to not have to go into as much technical detail as [3], because in all honestly I do not completely understand all of the math that is going on. Sources [1], [2], [6], and [9] all describe various methodologies for applying mathematical morphology to crack detection in digital art restoration, and will require the information drawn from [4], [5], [7], and [8] to be understood.

As background information on mathematical morphology, [4], [5], [7], and [8] are all highly related. Much of the information they relay is identical; however, slight variations and clarifications in how each goes about explaining the concepts make all seems worth keeping, at least for the time being. Sources [1], [2], [6], and [9] will make up the real substance of the paper, as they explain how morphological operators may actually be applied to crack detection in digital art restoration. Again, these are all closely related, but have enough variation that each contributes something meaningful. [2] provides an examination of the top hat transform and the bottom hat transform. [1] again looks at the top hat transform, but this time uses a multiscale variation. [9] looks at crack misidentification within the top hat transform. [6] is unique in that it uses a different morphological approach, but one that shares similarities with the top hat transform.

All four of the main sources [1], [2], [6], and [9] do implement the methodologies they describe and provide results. The main challenge in writing this paper, I believe, will be in presenting these results in a meaningful way, as due to the visual nature of the work, results tend to be qualitative rather than quantitative. However, [6] does present both a table and chart demonstrating the statistical rate of crack misidentification under various circumstances, and this may be the direction I choose to head in when presenting results within this paper.

In order for the audience to understand the material presented in this paper, they will need the information on mathematical morphology and its operations obtained from sources [4], [5], [7], and [8]. It would also likely benefit the audience to at least have a basic understanding of the concepts behind edge detection presented in [3]. While I hope to avoid as much assumption as possible, this paper will likely rely somewhat on an assumption that the audience has a basic understanding of the fundamental operations of set theory.

Outline

1. Introduction [1, 2, 6, 9]
   1. Concepts/Reasoning Behind Digital Art Restoration [2, 6, 9] – Explanation of why digital art restoration exists.
   2. How Cracks Form/Types of Cracks [1, 2] – Explanation of how cracks form, and will also probably briefly cover common crack variations.
   3. Applying Mathematical Morphology to Crack Detection [1, 2, 6, 9] – Explanation of the concepts behind mathematical morphology and how they may be applied to crack detection in digital art restoration.
   4. Summary of Next Sections – What it says on the tin.
2. Background [3] – Not entirely sure what is going to go here yet. What is listed currently is my best approximation. Some items from the introduction could possibly be moved into this section as well.
   1. Edge Detection Information [3] – Basic information on mechanics of edge detection. This is something that needs to be discussed in the context of this paper, but hopefully will not need to be terribly in-depth, because the math involved gets a little intense.
   2. Canny Algorithm [3] – Extension of section on edge detection. The discussion of edge detection will be general information, while this section will be focused on a specific method, probably with some equations involved.
3. Morphological Operations [4, 5, 7, 8] – Explanation of morphological operations. This will probably make up a significant portion of the final paper.
   1. Erosion [4, 5, 7, 8] – Explanation of erosion.
      1. Binary [4, 5, 7, 8]
      2. Greyscale [8]
   2. Dilation [4, 5, 7, 8] – Explanation of dilation.
      1. Binary [4, 5, 7, 8]
      2. Greyscale [8]
   3. Opening [4, 5, 7, 8] – Explanation of opening.
      1. Binary [4, 5, 7, 8]
      2. Greyscale [8]
   4. Closing [4, 5, 7, 8] – Explanation of closing.
      1. Binary [4, 5, 7, 8]
      2. Greyscale [8]
4. Methods of Crack Detection [1, 2, 6, 9] – Explanation of how the morphological operations described above can be applied to crack detection in digital art restoration.
   1. Top Hat Transform [1, 2, 9] – Explanation of top hat transform.
   2. Bottom Hat Transform [1, 2] – Explanation of bottom hat transform.
   3. Other Methods [6] – This source implements an unnamed method of crack detection. It is somewhat vaguely described at parts, and so this may not make the final cut, but for now it is listed.
5. Results [1, 2, 6, 9] – Presentation of results of the various methods of crack detection in digital art restoration explained in the above section. This section may include a discussion of crack misidentification, although it is also possible this will be discussed in the previous section on methods of crack detection.
6. Conclusions [1, 2, 6, 9]
   1. Summary of Previous Sections – What it says on the tin.
   2. Further Work – Explanation of inpainting, which is the next step in the digital art restoration process. Possibly a discussion of other methods of crack detection.
7. References
8. B. Cornelis, T. Ružić, E. Gezels, A. Dooms, A. Pižurica, L. Platiša, J. Cornelis, M. Martens, M. De Mey, and I. Daubechies. Crack detection and inpainting for virtual restoration of paintings: The case of the Ghent Altarpiece. *Signal Processing*, 93(3):605-619, March 2013.
   * This paper provides another methodology for crack detection and restoration in digital art.
   * This paper combines three detection schemes in order to capitalize on the strengths of each, and addresses problems encountered.
   * Results are provided, however, these are in the form of images, and therefore cannot be summarized here.
   * This paper provides a lot of information on crack detection and inpainting; however, for the purposes of my paper, I am really only interested in what it has to say on the application of the top hat transform, which may be used in conjunction with information presented in [2] and [9].
   * This paper is valuable in that it discusses the multiscale top hat transform.
   * Understanding of the information drawn from this paper will depend on a previous understanding of the top hat transform, which will be provided by the information drawn from [2] and [9].
9. G. S. Spagnolo and F. Somma. Virtual restoration of cracks in digitalized image of paintings. *Journal of Physics: Conference Series (249)*, 2010.
   * This paper provides another methodology for crack detection and restoration in digital art.
   * Results are provided, however, these are in the form of images, and therefore cannot be summarized here.
   * This paper provides a solid structure for the understanding of top hat transforms and bottom hat transforms, which may be used in conjunction with [9], and as a foundation for the more complex multiscale top hat transform presented in [1].
   * This paper does not assume much previous knowledge; however, the explanation of basic morphological operations presented here is somewhat unclear, and so the information provided by [4], [5], [7], and [8] should be helpful in understanding this material.
10. J. Canny. A computational approach to edge detection. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 8(6):679-698, November 1986.
    * This paper describes in detail a methodology for edge detection based on detection and localization criteria.
    * Results are provided, however, these are in the form of images, and therefore cannot be summarized here.
    * This paper provides background information on edge detection.
    * A previous understanding of convolution integrals is needed to understand this material; however, as this will mostly be used as background information, this knowledge will probably not be necessary in the contexts of my paper.
11. Morphological Image Processing. <https://www.cs.auckland.ac.nz/courses/compsci773s1c/lectures/ImageProcessing-html/topic4.htm>.
    * This source provides background information.
12. N. Efford. *Digital Image Processing: A Practical Introduction Using JavaTM*. Pearson Education, 2000.
    * This source provides background information.
13. N. Karianakis and P. Maragos. An integrated system for digital restoration of prehistoric Theran wall paintings. In *Digital Signal Processing (DSP), 2013 18th International Conference on*, pages 1-6, July 2013.
    * This paper provides another methodology for crack detection and restoration in digital art.
    * Results are provided, however, these are in the form of images, and therefore cannot be summarized here.
    * This paper demonstrates a methodology entirely unique from the other sources used, which all are variations on the top hat transform.
    * This paper assumes some previous understanding of the Canny algorithm described in [5], and also of basic morphological operations.
14. R. Fisher, S. Perkins, A. Walker, and E. Wolfart. Morphology. <http://homepages.inf.ed.ac.uk/rbf/HIPR2/morops.htm>, 2003.
    * This source provides background information.
15. R. M. Haralick, S. R. Sternberg, and X. Zhuang. Image analysis using mathematical morphology. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 9(4):532-550, July 1987.
    * This paper provides an in-depth description of the functions of the basic morphological operations of erosion, dilation, opening, and closing in the context of both binary and greyscale images.
    * No results, this is an informational source.
    * This paper does not assume any previous information; however, some of the information presented is very technical, and therefore is best taken in conjunction with the information provided by [4], [5], and [7].
16. S. D. Desai, K. V. Horadi, P. Navaneet, B. Niriksha, and V. Siddeshvar. Detection and removal of cracks from digitalized paintings and images by user intervention. In *Advanced Computing, Networking and Security (ADCONS), 2013 2nd International Conference on*, pages 51-55, December 2013.
    * This paper provides a methodology for removing misidentified cracks from crack detection results.
    * This paper also presents a nice summary of previous methods of crack detection and inpainting detailed in other papers.
    * Results are provided, in this case in table and graph format, demonstrating the accuracy of the methodology presented in identifying cracks under different classifications.
    * This paper assumes previous knowledge of the top hat transform, as this paper itself is more concerned with finding a solution to crack misidentification than in the initial detection process.