A Study of Digital Image Enhancement Techniques

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Abstract:
With the advent of technologies in the field of Computer Graphics, it has become possible to store, analyze and manipulate imagery data easily in digital format. Today, a large amount of data is available in the form of images also called as imagery data and the size of the data available in this format as well as its usage is increasing day by day. Many image classification and image processing based applications work in multiple use case scenarios which demand such data on a large scale in order to perform novel varied kinds of analysis on it and provide useful insights by making use of modern computer systems. However, in many cases, the available imagery data may not be in the format or quality which is best suited for the kinds of models being used. In addition to this, the quality of the images may not be such that the required useful details may be extracted from them by a computer-based system. As a result, it demands the use of certain techniques that play a role in rendering the required quality to the imagery data which is required by the Computer Vision or Image Processing based application under consideration. In addition to this, these techniques also help in providing or highlighting the information pertaining to certain specific aspects of importance related to the images as well as eliminating, suppressing or manipulating the details pertaining to certain unwanted aspects which is referred to as image enhancement. Image enhancement is considered an unavoidable task in the process of making the data ready for usage by the Computer Vision based systems. This paper aims to provide an overview of image enhancement and the techniques that are used for digital image enhancement.

Keywords: Computer Graphics, Computer Vision, Data Preprocessing, Enhancement Techniques, Filtering, Image Classification, Image Enhancement, Image Processing.

I. INTRODUCTION

Computer Vision is a field which makes use of many Deep Learning based algorithms, models, tools and technologies in order to extract information from image or video-based data resources, apply some analysis to it and provide useful insights to the users. It is also recognized as a branch of image processing that deals with computer-based processing of images that represent the real world. [1] Many research topics under this field like Image classification and Object detection among others include the use of algorithms or technologies that make use of imagery datasets on a large scale. Such technologies perform powerful visionary-based operations which make a machine or a system independent of performing the tasks which traditionally have been requiring human intervention. An example for this can be that of autonomous or self-driving cars which is a topic of research in which new techniques of using Computer Vision and Digital Image processing-based utilities are being devised that would enable the working of cars by obviating human efforts. As a result, while dealing with such complex and powerful real-world applications, the utilities being discussed need to work on a large amount of data which is in the form of images or video frames. Also, since many of these images are captured in the actual scenarios or environments where the models are deployed and used, it is difficult to obtain the consistent and idealistic quality of images at every instance which would be the same quality as that of the images on which the models have been trained on. This is mainly because the quality of images can differ based on the amount of light or darkness, introduction of noise, blurriness due to foggy environments and some other factors. [2][10] Hence, due to images having such degraded quality, the performance of the applications or models is hampered. [2] Due to such reasons, the systems find the need of mechanisms that are aimed towards fixing or restoring the quality of the images up to some extent or at least with respect to certain features of it that are of importance for the application before feeding the image to the model to work on. [10] In some cases, this requirement of enhancing the images may also be encountered in case of the data required for training of the models. This requirement of restoring the images to the required quality and diminishing the operational environment’s unwanted effects on them can be fulfilled by certain digital image enhancement techniques. [9][10] Overall, the concept of image enhancement deals with modifying the image with respect to one or more attributes in order to make it interpretable by the designated automated image processing system. [9] Image restoration slightly differs from the concept of image enhancement [2] as the primary aim of image restoration is to make the processed image as similar as possible to the original image. Whereas image enhancement aims towards making the processed image better than the original image obtained up to some extent. [2] But when an image of degraded quality is obtained, its restoration can result in its enhancement because of which the two concepts are related. [2] There are multiple image enhancement techniques and each one of these deal with a different aspect with respect to which an image is enhanced. These techniques are classified based on the class of the problems which they solve.

The classes of problems are [2]:
1. Enhancement by modifying contrast or dynamic range.
2. Enhancement by reducing degradation.
3. Enhancement where 2D image may not represent intensity of actual image.

The enhancement techniques discussed further deal with solving problems related to one or more of these classes.
2. SURVEY OF IMAGE ENHANCEMENT TECHNIQUES

2.1 Low-Pass Filtering
Low-Pass Filtering is an image enhancement technique which is used for minimizing additive random noises. Its working is based on a simple principle by virtue of which, it suppresses the high-frequency components and preserves the low-frequency components of the signal. [2] Hence, as the effective amount of reduction in the amount of signal is lower in this method, low-pass filtering is known for reducing a large amount of noise at the expense of reduction in lower amount of signal.

Since the low-pass filtering technique is known for reducing the high-frequency components of the noise that are present, this technique also suppresses the high-frequency components of the actual desirable digital signal as a side-effect. [2] Due to this, the resultant image is rendered as comparatively blurrier. [2][8] This is mainly because the edges in the image are the major contributors of the high frequency components which are suppressed during the process. As a result, because of this effect, this technique is sometimes also used to smoothen out certain background areas of the image. While doing this, the more desirable brighter spots present in the image remain unaffected. [8]

The low-pass filtering technique works by decreasing the amount of difference between the adjacent pixel values by effectively averaging out the neighboring pixels. [7] Following are the examples of matrices that are popularly used as low pass filters: [2][7]

\[
\begin{bmatrix}
1/9 & 1/9 & 1/9 \\
1/9 & 1/9 & 1/9 \\
1/9 & 1/9 & 1/9 \\
\end{bmatrix} \quad \begin{bmatrix}
1/10 & 1/10 & 1/10 \\
1/10 & 1/5 & 1/10 \\
1/10 & 1/10 & 1/10 \\
\end{bmatrix}
\]

Figure 1. Low-Pass Filters

The low-pass filtering technique makes use of a linear shift invariant operation by computing the moving average at every step and makes use of the filters that are shown in Figure 1. [2] The filters like those mentioned above are constructed according to requirements depending on whether different smoothing is required in different dimension or the amount of weighting that is required at the center. [7]

The efficiency and computational expensiveness of this technique depends on the support region associated with the filter which is being used. However, the performance can be improved by considering the adaptation of the filter with the image characteristics. Hence, the low-pass filtering technique is efficient in reducing the multiplicative or additive random noise but renders the image quite blurry as a side-effect. [2]

2.2 High-Pass Filtering
The High-Pass Filtering technique follows a basic principle which runs counter to that followed in Low-Pass filtering technique in terms of the type of component that is suppressed and the kind of component that is preserved. In this technique, the low-frequency components of the signal are suppressed whereas the high-frequency components are preserved. [2] Hence, since image sharpening is an outcome of preserving high frequency components, the use of high pass filters (used in high-pass filtering) is considered as a basis for various sharpening methods for the images. [7] Thus, counter to the effects observed in case of low-pass filtering, the image which is provided as a result of high-pass filtering is rendered sharper than the original image. [7]

As a result, one of the major uses of the high-pass filtering technique is for removing the blurriness of the image which is an undesirable feature that may have been obtained due to factors like motion of camera or the motion of the object being captured, atmospheric disturbance or defects in the camera lens. This technique is also used as a preprocessing step in many Computer Vision-based applications. A high pass filter is applied on the images before the images undergo degradation and a low pass filter is applied after the degradation. [2] This method helps improving the quality of the image and reducing the effects of the degradation on the image.

The high-pass filtering technique works by enhancing the contrast between the adjacent regions of pixels that have small variations in darkness or brightness. [7] These changes in contrasts in turn render the image sharper. Following are the examples of matrices that are popularly used as high pass filters: [2][7]

\[
\begin{bmatrix}
-1/9 & -1/9 & -1/9 \\
-1/9 & 8/9 & -1/9 \\
-1/9 & -1/9 & -1/9 \\
\end{bmatrix} \quad \begin{bmatrix}
0 & -1 & 0 \\
-1 & 5 & -1 \\
0 & -1 & 0 \\
\end{bmatrix}
\]

Figure 2. High-Pass Filters

Like the low-pass filtering technique, the high-pass filtering technique also makes use of a linear shift invariant operation using the above filters and by computing moving average at every step. The high-pass filters are aimed towards increasing the brightness of the central pixel as compared to the pixels surrounding it. Due to this reason, the filters are constructed generally by placing a positive value at the center. [7]

As mentioned in case of low-pass filtering as well, the background areas of the images in most cases make use of the high-frequency components which were being smoothened out in case of low-pass filtering. However, this technique tends to increase the power of background noise when it is applied to an image that has undergone degradation. [2] This feature of the technique is considered as a major limitation since making the background noise powerful is not desirable in many cases.

Thus, this technique is considered useful in scenarios where the image to be processed is available before undergoing degradation so that the technique can be applied on it. It is also useful where the amplification of the background noise components won’t hamper the system colossally.

2.3 Gray-Scale Modification
The gray-scale in case of images consists of a range of shades of gray color where the shades show a gradual change of darkness or lightness over the entire range. [6] The gray-scale modification technique is considered as an effective way of altering or modifying the dynamic range and other relevant characteristics of images. [6][2] In this technique, a specific kind of transformation is determined. After that, the gray-scale of an image that is provided as input is changed to a different gray-scale corresponding to another level by making use of the predetermined transformation. Thus, the mentioned transformation is use to determine a corresponding value based on the new gray-scale for the value based on the existing gray-scale. A graph of the existing scale versus the
new scale values is also obtained to map the corresponding values. [3]

In this method, initially a histogram based on the transformation is obtained for an image. This is generally done before the image is processed. After processing the image, another transformation is determined such that the histogram created by considering this transformation will approximately be the same as the earlier one for an image. While performing this, two cumulative histograms, one each for the image before processing and one for the output image are also determined. [2][3]

The determination of a histogram is a useful method under this technique which is a way of representing the exact number of pixels in a given image having a particular intensity. [2][3] Thus, this method helps in scrutinizing the characteristics of the image which help in determining the gray-scale transformations that suit the requirements. In general, it is followed that if a table containing all the entries for the values obtained from the transformation is constructed, the total number of entries will be $2^M$, where $M$=total number of bits used for the gray-scale. [2]

As a result, the overall technique is computationally simpler to implement since it works by considering only a limited number of values. In many cases, the image can be rendered as sharper and more pleasant than the input image. Certain details of the images can be made clearer and more visible by this method by making some changes like increasing contrasts. This technique is mainly useful in scenarios where the changes or the transformations need to apply for all the parts of the image. This means that all the transformations will apply globally for every region of an image. [2]

2.4 Median Filtering

In the median filtering technique, a filter is used which is made to slide over an image and determine the median value of the intensities of the pixels under the filter window. [4][3][2] After determining this median value, the intensity value of the pixel that is being processed is changed to this value. This median filter is particularly a non-linear filter. The median filtering technique works towards reducing the noise level and overall smoothing of the image. [3] Due to this characteristic its functioning is termed as similar to that of the low-pass filtering technique. This technique is better in terms of dealing with values that appear as outliers as compared with the rest of the data. [4] Since the mean value is affected by the outliers, the performance of the mean filters is hampered by the presence of extreme values within a set of values. On the contrary, the median value is not affected by the presence of a few outliers, thus the performance of median filters is considered more reliable and accurate as compared to the mean filters. [4]

In addition to all this, another important characteristic of the median filter is that it shows a better performance as compared to other filters when it comes to preserving sharp edges in the images. [3] Thus, the median filtering technique does not affect the discontinuities even if they are present in large numbers in the images. The size of the window used for the filter is an important feature in this technique on which the overall performance depends. In many cases, it is difficult to predetermine the window size. [3] As a result, windows with multiple sizes pertaining to different median filters are tried on the data and the one showing the best performance is selected as the final one. [3][2]

Median filtering is also known for its ability of preserving spatial resolution while suppressing isolated pixels or lines. Also being a non-linear function and being defined in the spatial domain, it is easier to implement this technique in the spatial domain. [3] In many cases, the median filter technique can be observed to be more complex and computationally expensive as well as time consuming. This is mainly because of the requirement of the calculation of the median value at every step. [4]

Even though the median filters are not successful in reducing all types of noise, they prove to be successful in case of most types of noises. The noises like salt-pepper noise, gaussian noise, blurriness due to motion and blurriness due to defocus can be diminished by using this technique. [4] However, in case of problems like uniform noise or gaussian blur, this technique does not show satisfactory results. [4]

Thus, the median filtering technique is preferred in scenarios where problems related to particular types of noises have to be dealt with which can be solved by median filters. It is also preferred in scenarios where the discontinuities have to be preserved, as such preservation is a special highlight of the abilities of this technique.

2.5 Adaptive Filtering

There are multiple scenarios where the application of a single operation to every region of the image is not efficient from the point of view of image enhancement. This is because the information pertaining to certain features which are used to determine the kind of degradation problem as well as the kind of rectification required is not known in advanced. These features also include the type of the images that are going to be fed as input for processing. In such cases, adaptive filters can be used when it is not known whether the information pertaining to the parameters is going to remain constant or not. [5]

This technique also allows to enable selective filtering in order to better increase the efficiency of the system by focusing the enhancement process on specific parts of the images where it is required instead of applying it on all the parts by default. [5] As a result, the working of this technique follows a kind of dynamic approach and obviates the method followed in techniques like low-pass filtering where the process is applied to each and every part of the image. [5]

For this, an example associated with an image affected by wideband random noise can be considered. [2] While enhancing such an image the local variance feature of the image can be considered. This local variance value will mostly be higher in those parts of the images which contain the high frequency components which are generally included under discontinuities or sharp edges. Thus, the noise components are generally less visible in such regions which contain the high frequency components of the signal. [2] As a result, there is no need to apply smoothing to such parts of the images. Hence by considering local variance as a feature and determining its value for every region of the image, it can be found out whether the high frequency components are present in that particular region. Following this, in case they are not present, then the required smoothing can be applied to that part of the image. But on the other hand, if these components are present,
then that particular region of the image can be skipped while smoothing the parts of the image. [2] In this way, selective enhancement and application of the process can be achieved for specific regions of the image as per requirement using the adaptive filtering technique.

The adaptive filtering technique is used in scenarios where high performance is required in case of image enhancement problems as this technique provides efficient and selective application of processing.

3. ADVANTAGES AND DISADVANTAGES OF DIGITAL IMAGE ENHANCEMENT TECHNIQUES

Table 1. Advantages and Disadvantages of various techniques

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Technique</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Low-Pass Filtering</td>
<td>1. Reduces additive as well as multiplicative noise.</td>
<td>1. Renders the images blurry.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Performance can be improved by using adaptive techniques.</td>
<td>2. Can be computationally expensive in some cases.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Evenly smoothened images can be obtained.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Useful where sharpening of images is a preprocessing requirement.</td>
<td>2. Can be computationally expensive in some cases.</td>
</tr>
<tr>
<td>3.</td>
<td>Gray-Scale Modification</td>
<td>1. Simpler to implement.</td>
<td>1. All operations are applied globally to all the images.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Less expensive computationally.</td>
<td>2. The operations for some images may or may not be suitable for others.</td>
</tr>
<tr>
<td>4.</td>
<td>Median Filtering</td>
<td>1. Useful in cases where discontinuities have to be retained.</td>
<td>1. Can be computationally expensive.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Useful in reducing multiple types of noises.</td>
<td>2. Complex to implement.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Median calculation is not affected by outlier intensity values.</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Adaptive Filtering</td>
<td>1. High performance in image enhancement as compared to other techniques.</td>
<td>1. Can be computationally expensive.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Useful in cases where operations have to be performed in a more specific manner.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Complex.</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

Image Enhancement is a very important activity when datasets containing varied types of images are to be used for modern, complex Computer Vision-based applications. These techniques are aimed towards enhancing the quality of the images with respect to one or more aspects or features. The images with enhanced quality are not only understandable but also useful to ensure accurate results as output from the applications that work on them. Without the right quality, the decline in performance of these applications is likely to take place due to failures in capturing the right details from the images. There are multiple types of problems associated with image degradation each of which has different causes and effects. However, implementation of suitable enhancement techniques can help in mitigating the effects of these problems by modifying the images with respect to one or more features in order to counter those problems. In this way, such image enhancement techniques also prove to be effective data preprocessing steps. Multiple image enhancement techniques including the ones mentioned in this paper aim towards solving one or more classes of problems. Such techniques are helpful in multiple inter-related fields like Computer Graphics, Computer Vision, Image Processing and Video Processing. Thus, these techniques contribute in making the data ready for multiple advanced real time applications.

V. REFERENCES


