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| **Adaptive Weighted Median Filter To Remove Impulsive Noise** |

**ABSTRACT - An improved adaptive dynamically weighted median filter is proposed to better remove the impulsive noise from the distorting image based on the algorithm of ADWMF. The window size can be dynamically changed due to the number of noise pixels and the noise removal of boundary is optimized by the adjustable window size. Experiment results show this improved median filter has a better performance.**

1. **Introduction** 
   1. **Motivation**

No matter willing or not, robotic technologies are involving into people’s life, like the vision system on automatic driving vehicles, which is powered by different sensors and information processing systems.

Based on the ‘introduction to Autonomous Mobile Robot’, there are several general classifications based on typical application for the sensor. For instance, Vision sensors (like CCD/CMOS camera, Visual ranging packages and Object tracking packages) can measure visual ranging, whole-image analysis, object recognitions, etc. [2] The information processing system is used for filtering the noise in the image by several different filters. There are different kinds of noise including Gaussian noise, pepper/impulsive noise, etc. Noise can be filtered by median filter, gaussian filter, mean filter, etc. [6] This paper focused on researching the impulsive noise removal by median filter for the image captured by the vision sensors.

One of reasons to pick this topic is that the working quality of image filters relates to the working quality of robotics. The vision sensors (like cameras) are the eyes of robotics, which converts the image to the digital form, and image filters are the nerve center of robotics which process the image and let robots understand what they have seen and make more accurate decisions for their next steps, like navigation, localization, etc. Another reason is that the each second of video is made of dozens of pictures, which means if we would like to develop the skill to higher level of video processing technology (which requires filtering dozens of pictures within one second), developing strong coding skills on designing image filters is the first challenge and very good start. The third reason is that, Tesla had announced it is trying to reduce the sensor on its car to eight cameras around its cars, which means the Tesla car’s auto driving system would only rely on visual sensors, and the image filtering technology under the image processing system must be one of hot researching topics in recent years.

Because image filters are important parts of image processing system, very good start for video processing system and hot topic for recent years, the median filter of image filters which is used for filtering impulsive noise is chosen as main topic.

* 1. **Application**

In image processing technology field, noise removal is an important task. There is a bunch of papers concerning about various filters to remove different kinds of noise. Basically, it alters images’ pixels with desired form with different types of graphical editing methods through a graphic design and editing software [1]. For the robots with movement, the noise of the images captured by camera includes Gaussian noise and impulsive noise. The impulsive noise is related to the external environment interference while the Gaussian noise would be influenced by the device and electrical system [3]. So, the problem is how to remove the image noise better. This paper discusses the traditional medium filter method and the adaptive medium filter which is updated based on the disadvantages of traditional medium filter.

* 1. **Related work**

A lot of research about how to improve the median filter has been done until now. Hanglin and Yuanzhong[An Improved Algorithm for Impulse Noise by Median Filter] proposed an algorithm that can choose better thresholds and filtering templates for median filters, so that enhance the ability of impulsive noise detection. Toh and Isa[8] proposed an adaptive median filter, which would expand the size of slide window when there is no noise-free pixel inside. Vijaykumar et al.[9] improve the performance of median filter by dividing the process into two stages, including impulsive noise detection and noise removal. When less than two absolute differences between the center pixels and other pixels inside the window are greater than threshold, then the center pixel would be considered as a noise pixel. Recently, with the development of the deep learning, some researchers start to combine the median filter with these technologies. Jacek and Tomasz[CELLULAR NEURAL NETWORK BASED WEIGHTED MEDIAN FILTER FOR REAL TIME IMAGE PROCESSING] proposed a weighted median filter based on the CNN architecture for the real-time application.

1. **Definition**

Image noise comes from different aspects that can be divided to internal and interference sources, while internal sources include electric, heat and sensor illumination levels, the interference sources may from the strong electrical transmission in the environment. In this paper, the impulsive noise from internal sources will be discussed and filtered.

The impulsive noise, also be known as ‘Fat-tail distributed’ or ‘pepper noise’, is manifested as pixels erroneously reporting bright readouts in black parts of the frame or dark readouts in bright parts, which looks like mixed white salt and black peppers [7]. The impulsive noise may be caused by analog-to-digital conversion. [7]

Median filter is a useful method for removing speckle noise salt-and-pepper noise since median filter does not adopt weighted average method for calculating filtered result. In classical median filter, the center pixel of a n\*n neighborhood is replaced by the median value of the corresponding window. And in classical filter, the noise pixels are very different from the median value [4].

However, as the classical median filter uses ‘health’ value around pixel value to replace it, when the pixels are concentrated at a part of the image, the value around pixel values are still pixels. That’s the reason why a new adaptive median filter is talked in this paper. Although its main idea is still using the ‘healthy’ value to replace the pixel value, it can change scanning box size around this pixel. The more pixels in a certain area, the larger the scanning box would be and there will be more ‘healthy’ value be included to replace pixels in this box.

1. **Proposed works**

To avoid the situation that bunch of noise pixels gather in specific area, which would cause the noise value to become the median value in that area if the static slide window is used, some enhancements are made to original median filter. After referring to the algorithm of noise detection that proposed by Ghanekar [] and the adaptive noise removal algorithm proposed by Sajid[], an improved adaptive dynamically weighted median filter (ADWMF) is proposed in this paper. The size of slide window can be adjusted, depending on the number of noise pixels inside it.

The adaptive dynamically weighted median filter contains two stages: noise detection and noise removal. Because the change of slide window size is dependent on the number of noise pixels, the position of those noise pixels should be firstly detected. Figure 1 shows the flowchart of the noise detection algorithm. The steps are given as:

1. Create and move 3x3 slide window for every pixel I(i,j) in image I.
2. Check the central pixel value, if it is extremum inside the slide window, it would be picked as a potential noise pixel candidate.
3. Use 11x11 slide window to select final noise pixels. This time the window only moves across every pixel I(i',j') in noise pixel candidates list.
4. Sort pixels values in ascending order and get a new list R'.

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| Diagram  Description automatically generated |
| **Fig. 1** Flowchat of noise detection algorithm |

1. Compute the distance list by subtracting the previous term from the next term in R'.
2. Pick up the four largest distance and store their indices as i,j,k,l.
3. , , if the central pixel value is smaller than or is larger than , then it is the noise pixel. Otherwise, it would be defined as a noisy free pixel.

There is one special situation that when , it is impossible for any pixel value to be smaller than zero, then the noise pixels would not be detected under this condition. That’s the reason for adding an extra if statement to judge whether the value is larger than zero.

The output of noise detection algorithm is a binary image where 0 represents noise-free pixel while 1 indicates the noise pixel.

After detecting the position of noise pixels in images, the second stage is to remove those noise. The general idea is that expanding the size of slide window based on the number of noise pixels inside it.

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| Diagram  Description automatically generated |
| **Fig. 2** flowchat of noise removal algorithm |

The input is the noise image and the binary image got from the noise detection algorithm. Figure 2 show the flowchart of this algorithm. The steps of noise removal algorithm are given as:

1. Use 3x3 slide window to count the number of noise pixel inside it. If it is smaller than 4, the size would be kept using in weighted median filter module. Otherwise, the size would be expanded to 5x5.
2. When the size of slide window has been changed to 5x5, count the number. If the number of noise pixels is smaller than 12, the size would be kept using in weighted median filter module. Otherwise, the size of slide window would be expanded again to 7x7.

For the weighted median filter, the algorithm is:

1. Generate the windows with same size for noise image () and binary image () for the central pixel in the same position.
2. Generate the Gaussian Surface that has the same size with the windows.
3. Compute by the equation: . convert the weight of noise pixel to be 0. After multiplying the Gaussian surface, those noise pixel value would be removed and won’t engage in the calculation of median value anymore.
4. The elements in are just like frequency, the times that adding the pixel value into a list A is based on the element value on the same position.
5. Sort the A in ascending order and compute its median value. Replace the center pixel value in noisy image by this new one.

Through this way, when center pixel is noisy or its nearest neighbors are noisy pixels, giving zero as their weight can help reduce the probability of selection of noisy pixel as median value, especially for the small size of slide windows.

However, when using this algorithm to deal with the boundary of the image, at first the window size is 3x3, if the number of noise pixel is larger than 4, the size would be changed to 5x5. That causes to the overflow problem. In this situation, an adjustment is made in this algorithm, the overflow pixel would be omitted and the even though the center pixel position changed, a flag would be added to the original center pixel, so that the updated value can still be given to the original center pixel.

1. **Results**

During the experiments, ADWMF was compared to the original median filter (MF), in which every pixel value would be changed to the median value in 3x3 window. Figure 3 shows the set of images that generated by algorithm.

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| A person wearing a hat  Description automatically generated with medium confidence | A picture containing text  Description automatically generated |
| a) | b) |
| A person wearing a hat  Description automatically generated with medium confidence | A person wearing a hat  Description automatically generated with medium confidence |
| c) | d) |
| Figure 3: set of results | |

Performance evaluation was done based on the peak signal-to-noise ratio (PSNR). PSNR is the ratio between the maximum possible value of a signal and the power of distorting noise that affects the quality of its representation. The equation of PSNR calculation is given below:

where MSE is the mean square error, the equation is given below:

The smaller MSE of noise-removal image is much preferred, because it shows the noise-removal image is much like the original image, which means the better performance of the filter. The smaller MSE causes the larger PSNR. Therefore, larger PSNR implies the higher quality of the images.

In the experiments, the impulsive noise will be added on the original image randomly. After 10 times execution done, the result is shown in the table 1

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| Table 1 | | |
| PSNR | MF | ADWMF |
| 1 | 12.95 | 13.16 |
| 2 | 15.23 | 15.66 |
| 3 | 14.94 | 15.32 |
| 4 | 14.38 | 14.75 |
| 5 | 14.97 | 15.36 |
| 6 | 14.08 | 14.36 |
| 7 | 15.62 | 16.10 |
| 8 | 16.09 | 16.65 |
| 9 | 14.08 | 14.39 |
| 10 | 14.13 | 14.47 |

Through the experiment, it is apparent that the ADWMF generate noise-removal images with high quality and have better performance, compared to the original median filter.

1. **Conclusion**

An improved adaptive dynamically weighted median filter is proposed in this paper. The number of noise pixels decides the size of slide window, which is based on the noise detection algorithm from Ghanekar []. Also, the gaussian surface is used to become the weight of each pixel, so that the possibility to pick up the noise-free pixel value will be improved. For the boundary noise removal in image, the window size would be shrunken depend on the position of center pixel. The algorithm is implemented by python. And experiment verified it has better performance when compared to original median filter, because its PSNR is always higher.

Until now, the adaptive median filter which can almost remove all the pixels from image has been successfully created. But there are still lots of work to do

Firstly, the processing time is too long. Although pixels are filtered with more adaptive way, it requires more steps than classical median filter. The classical median filter just needs to replace pixel with median value, but the adaptive median filter needs to locate the pixel, confirm it, update the box size based on the number of pixels within a certain area. So, the next step is reducing the processing steps, and accelerating filtering speed.

Second, even though the adaptive median filter works very well on filtering pixels, it does not have significant advantage over classical median filter. The main problem is that pixels are adding randomly and uniformly in the picture during testing the adaptive median filter, instead of being concentrated on one part of the image. In the future experiment, the code will be updated and pixels will be concentrated to test the system under extreme condition.

The third work needs to be finished is fixing the edge problem. When the pixel locates on the edge of the image, the box would cover too many areas which do not belong to image. Even though these areas’ value can be as 0s, it will change the median value. To avoid this effect, the fixed 3X3 size box is used on the edge instead of adaptive box which is used in the center part of image. In the future, this problem will be fixed by reviewing more research papers which talk about the problem of image processing on the edge, and applying adaptive box on the image’s edges.

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