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Edge detection of Friction Stir Welded Joints by using Laplace and Fourier Transformation

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Abstract

Visual inspection has played a vital role in the beginning era of science. Nowadays, image processing is finding application for defects analysis of the manufactured parts in many industrial processes. We have implemented two machine learning-based image processing techniques in recent work, i.e., Fourier Transformation operator and Laplacian operator for the surface defects detection in Friction Stir Welded joints. The quality of the weld surface in the Friction Stir Welding process depends on the input parameters such as Tool Rotational Speed (rpm), Tool Traverse Speed (mm/min), and an Axial Force (kN).

Keywords

Machine Learning,

Computer Vision,

Fourier Transform,

Friction Stir Welding

1. Introduction

Computer vision generally deals with the study of perceptible data. In the last couple of years, the proportion of visual data in the world has drastically increased to a ridiculous degree. A large proportion of perceptible data is produced globally due to many sensors, for example, cameras. So it is desired to design an algorithm that can further utilize and understand these data. The main problem with the visual data is that it is difficult to acknowledge. So due to this reason, visual data is represented as a dark matter of the internet in analogy to the dark matter in physics [1].

Computer vision is an interdisciplinary branch which explores the various area of science, engineering, and technology. The antiquity of computer vision harks back to approximately five hundred and forty-three million years ago. At that time, the earth was mostly water, and few animals were floating around in the ocean. Animals did not move around much at that time; they did not have eyes. So whenever food swims nearby, they grab them; otherwise, they float around. Something remarkable happened 540 million years ago. From fossil studies, zoologists found that the number of animal species just exploded within a brief period. Andrew Parker, an Australian zoologist, studied the cause and proposed one of the most

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convincing theories from fossils' studies. He concluded that five hundred and forty million years ago the eyes were developed by the first animals' and this outbreak of the vision started explosive speciation chapter. After 540 million years, the idea has evolved into almost all animals' humongous sensory system, incredibly quick-witted animals like humans. Nearly 50 percent of the neurons in our cortex are involved in visual processing, which is the powerful sensory system that enables us to survive, move around, work, communicate and maneuver things [5].

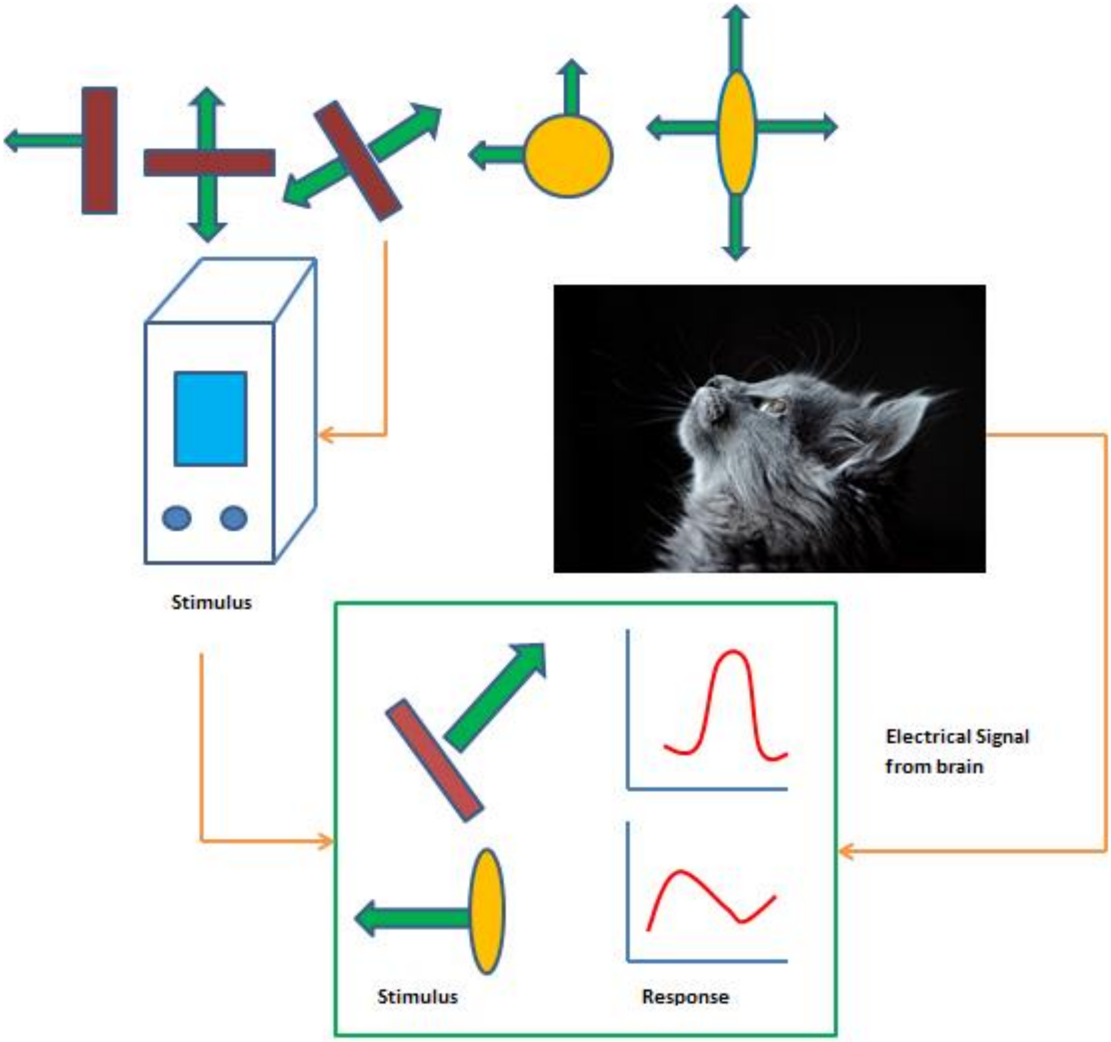

Figure 1: Visual Processing mechanism of a cat

In the meantime, the mechanism of the vision system gained some attention from biologists. In the 50s and 60s, Hubel and Wiesel [9], one of the most noteworthy works in both human visions and the animal vision that galvanized the computer vision. They chose the cat's brain for studying the mechanism of visual processing, as shown in Figure 1. From a processing point of view, a cat's brain is similar to the human mind. They stick electrodes at the back of the cat's brain in the central visual cortex area region. They noted that there are many types of cells in the cat brain's primary visual cortex. One of the most predominant cells in the superficial cells that respond to the edges' orientation when they propagate in a specific direction. It was discovered that visual processing begins with a simple structure of the graphic world-oriented edges. As the information propagates along the visual processing pathway, the brain constructs up the visual information's complexity until it recognizes the compounded visual world. The history of computer vision also starts around the early 60s. Block world is a set of work published by Larry Roberts, widely known as one of the first Ph.D. thesis of computer vision, where the visual world was simplified into simple geometrical shapes. The goal is to recognize them and reconstruct what these shapes are.

Computer vision finds application in the detection of surface defects. Li et al. [10] proposed an image processing technology for the detection of surface defects in an apple. Adel et al. [11] developed a computer vision system for the detection of defects in the wood by using a color analysis algorithm. Sarkar et al. [12] designed a machine vision-based inspection system for the quality separation of fresh market tomatoes. The computer vision system has also been used in the Friction Stir Welding process [13]. Mishra et al. [14] used a convolutional neural network for distinguishing the texture of the Friction Stir Welded joint from the conventional welded joint.

In recent work, Fourier transformation is utilized by using Python programming executed on the Google Colaboratory platform for the edge detection of Friction Stir Welded joints.

2. Material and Methods

Firstly, AA 1200 aluminum plates of dimensions 150 mm X 100 mm X 6 mm were clamped on a fixture mounted on the CNC machine. The fixture's primary function is to hold the two alloy plates at their initial position so that they may not dislocate from their initial work while carrying out the Friction Stir Welding Process. Secondly, the H13 tool was mounted into the spindle, and it was coded to give a tool rotational speed of 2000 rpm and a further traverse speed of 20 mm/min. Thirdly, a digital image of the welded joint's surface, was captured by a digital camera in RGB format. It was further subjected to the cropping process to obtain the region of our interest, shown in Figure 2.

Figure 2. Cropped Image of Friction Stir Welded joint

The cropped image is further uploaded to the Google Colaboratory platform, and it is subjected to two machine learning-based image techniques, i.e., Fourier transformation operator and Laplacian Operator.

Figure 3 shows the step by step procedure to which the cropped image is being subjected during Fourier transformation.

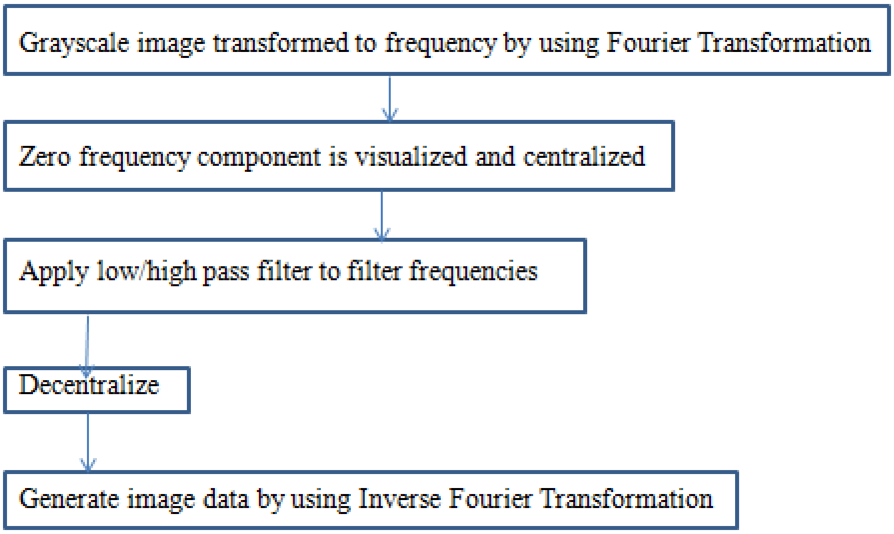

Figure 3. Process flow of the experiment

Figure 4 shows the procedure for implementing the Laplace operator on the cropped image.

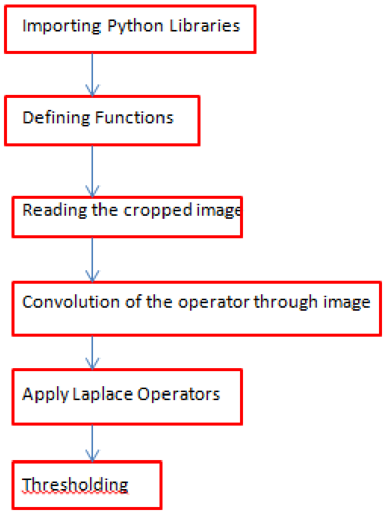

Figure 4. Laplace Operator implementation on the cropped image

3. Results and Discussions

Neighborhood operators who are sensitive to changes are mostly used for the task of the edge detection process. In the feature image, those parts that have undergone any change appear bright while the other part remains dark. The following subsections will highlight the results and will be discussed further.

3.1 Implementation of Fourier Transformation Algorithm

The Fourier transform is an extension of the Fourier series, which is generally used for periodic continuous signals. Fourier transform generally takes care of non-periodic signals. When we apply to transform into something, we retain the information captured in the original data, but we display it differently. If we take the Fourier transform of an image, we move it from the initial domain to the frequency domain. Fourier transform usually gives the frequency components present in the image. To develop the Fourier transform, assume that there is any continuous function f(x). So, the Fourier transform is obtained only when f(x) is both continuous and integrable. Equation 1 shows the Fourier transform of f(x).

$$\{f(x)\} = F(u) = \int_{-\infty}^{\infty} f(x)e^{-j2\pi ux}\ .dx \qquad (1)$$

ux is a frequency variable. If F(u) is integrable, we can also find out inverse Fourier transform shown in Equation 2.

$$f^{-1}\ \{F(u)\} = f(x) = \int_{-\infty}^{\infty} F(u)e^{j2\pi ux}.dx \qquad (2)$$

Equations 1 and 2 are known as Fourier transform pairs. Digital Image is generally a 2-Dimensional function of x and y. So, Equation 1 can be expanded to obtain Fourier transform in 2-dimension, as shown in Equation 3, and also further Inverse Fourier transform can be obtained as shown in Equation 4.

$$F(u,v) = \iint_{-\infty}^{\infty} f(x,y)e^{-j2\pi(ux+vy)}.dx.dy \qquad (3)$$

$$f(x,y) = \iint_{-\infty}^{\infty} F(u,v)e^{j2\pi(ux+vy)}.du.dv \qquad (4)$$

The 2-dimensional Fourier transform spectrum for the cropped image of Friction Stir Welded joint is shown in Figure 5 and can be further represented in a mathematical Equation 5. The phase angle is given by Equation 6.

$$|\ F(u,v)| = [R^2(u,v) +\ I^2(u,v)]^{\frac{1}{2}} \qquad (5)$$

$$\emptyset(u,v) = tan^{-1}\frac{I(u,v)}{R(u,v)} \qquad (6)$$

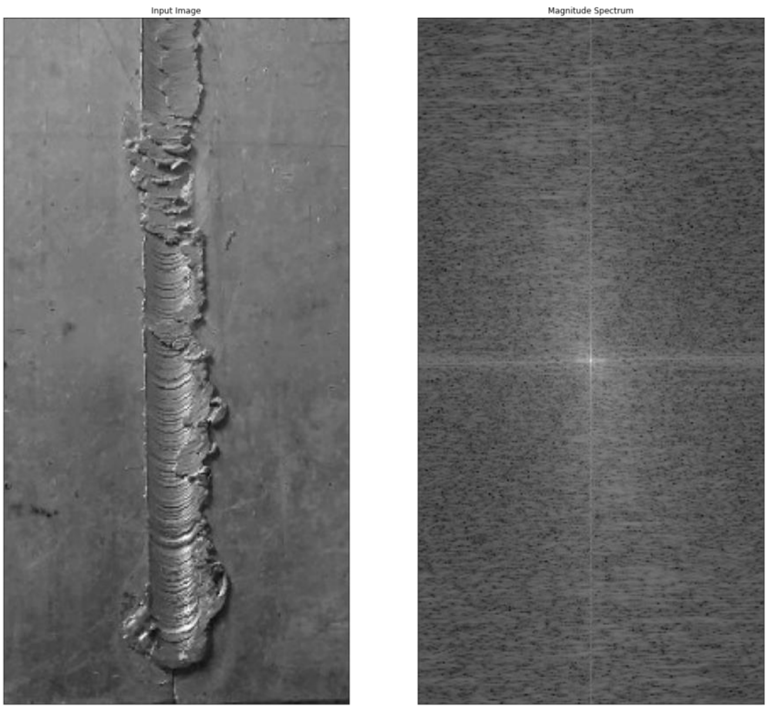

Figure 5. Magnitude Spectrum of the cropped image

Filters are subjected further to smoothen and sharpening the image by removing very high or low-frequency components. Filters are generally divided into two categories, i.e., Low pass filter and a high pass filter. Low pass filters have many functions, such as removing the noise from images, smoothening the appearance, removing high-frequency components, and keeping low-frequency components. A high pass filter is responsible for eliminating low-frequency components by further keeping high-frequency components and sharpening the image. In this research, Gaussian High Pass Filter has been used as shown in Figure 6 and 7, and it is mathematically expressed as Equation 7.

$$H = 1 - e^{\frac{-D^2(u,v)}{2D_0}} \quad (7)$$

In Equation 7, D_0 is a non-negative integer while D (u, v) is a distance of some point (u, v) from the origin as shown in Figure 8.

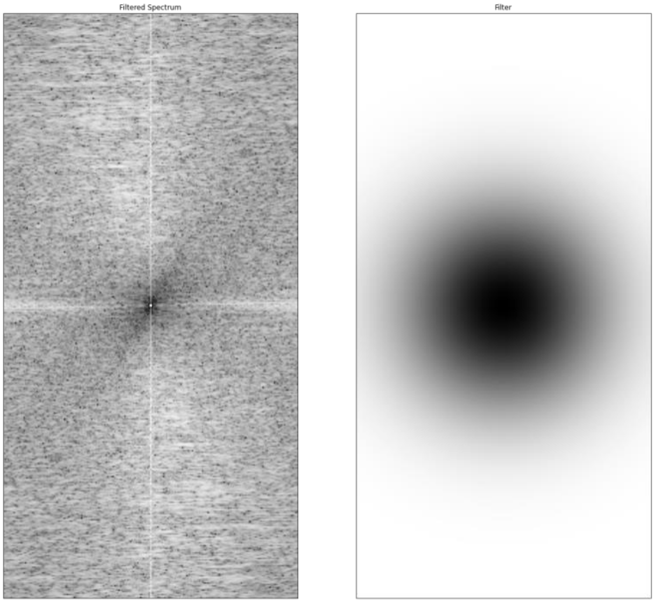

Figure 6. Gaussian High pass filter subjected to spectrum

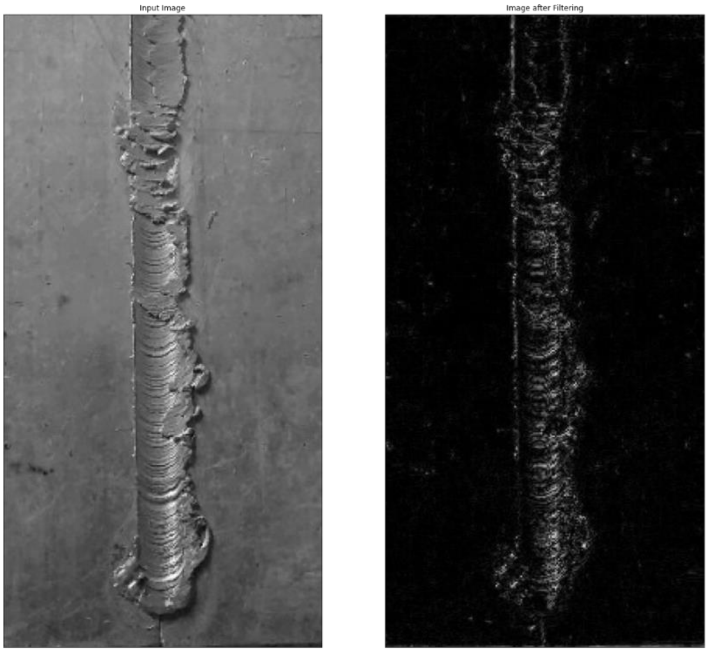

Figure 7. Gaussian High Pass Filter subjected to Cropped input image

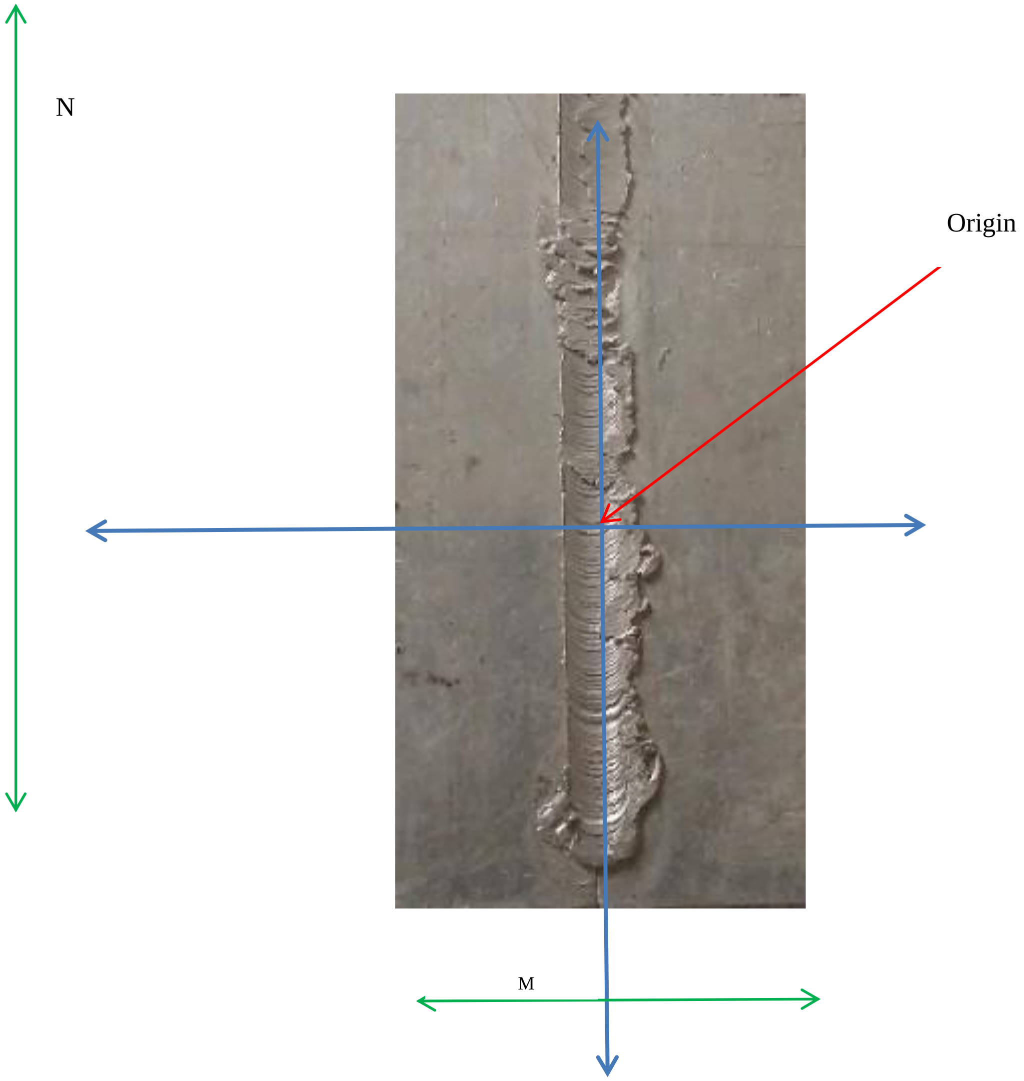

Figure 8. Representation of 2-dimensional image

Figure 8 D(u, v) can be calculated by Equation 7.

D(u, v) = sqrt ([$(u - \frac{M}{2})^2 + (v - \frac{N}{2})^2$]) (7)

It is observed from Figure 7 that the Gaussian high pass filter can detect rough surface and groovy edges present on Friction Stir Welded joint.

3.2 Implementation of Laplace Operator

Equation 8 defines the Laplacian operator.

$$\nabla^2 f = \frac{\partial^2 f}{\partial^2 x} + \frac{\partial^2 f}{\partial^2 y} \quad (8)$$

Where the partial first-order derivative in the x-direction is as follows:

$$\frac{\partial^2 f}{\partial^2 x} = f(x+1,y) + f(x-1,y) - 2f(x,y) \quad (9)$$

And in y-direction is given as follows:

$$\frac{\partial^2 f}{\partial^2 y} = f(x,y+1) + f(x,y-1) - 2f(x,y) \qquad (10)$$

After combining Equation 9 and Equation 10 , we obtain a second derivative operator i.e. Laplacian Operator as shown in Equation 11.

$$\nabla^2 f = [f(x+1,y) + f(x-1,y) + f(x,y+1) + f(x,y-1)] - 4f(x,y) \qquad (11)$$

Laplace filter can easily be constructed based on Equation 11 as shown below.

F(x-1,y-1)	F(x-1,y)	F(x-1,y+1)
F(x,y-1)	F(x,y)	F(x, y+1)
F(x+1,y-1)	F(x+1,y)	F(x+1,y+1)

In the recent work, we have used Laplace 4-neighborhood and 8-neighborhood operator as shown below.

$$Laplace_{4-neighborhood} = \begin{matrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{matrix}$$

$$Laplace_{8-neighborhood} = \begin{matrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{matrix}$$

The image obtained is shown in Figure 9. It is observed that Laplace 8-neighborhood filter provides better quality image resolution and the characteristics such as surface defects present on Friction Stir Welded joint can be better inferred in comparison to Laplace 4-neighborhood filter operator.

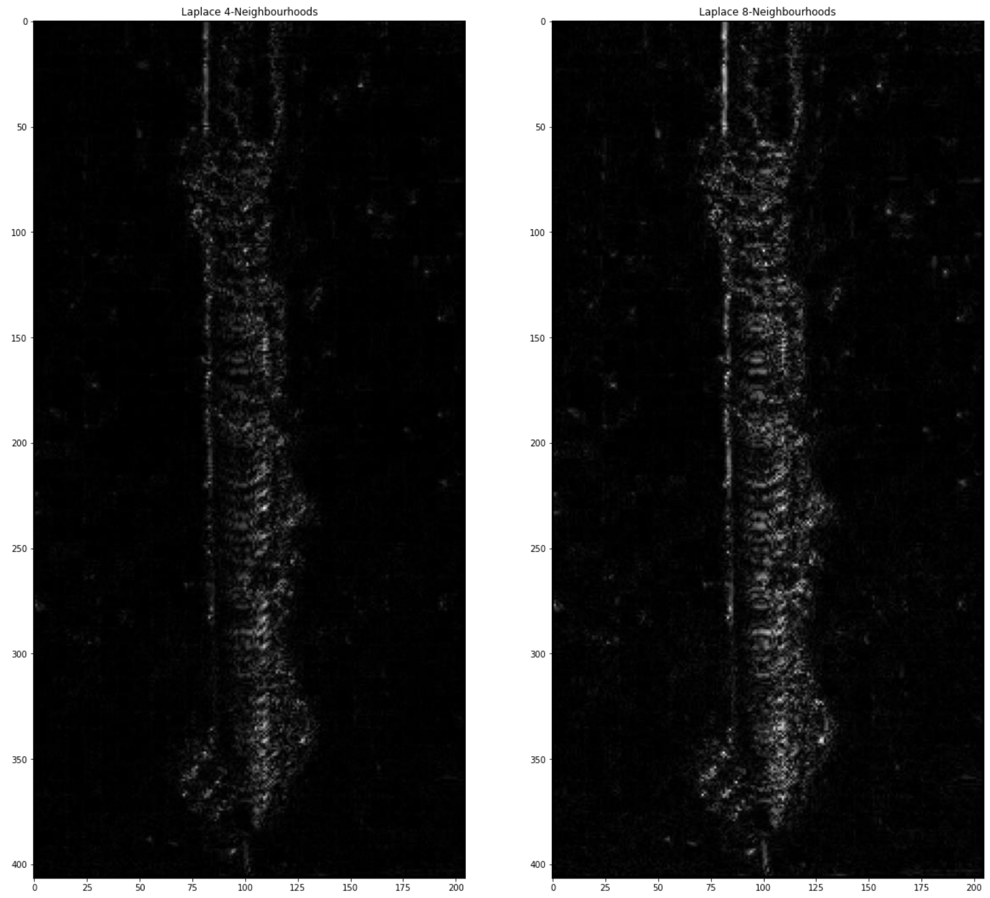

Figure 9. The cropped image has undergone Laplace transformation

4. Conclusions and Future Work

The research has implemented machine learning-based image processing techniques, i.e., Fourier Transform and Laplace transform operator. The results showed that the Friction Stir Welded joint's surface defects can be successfully detected by using these techniques. It is also observed that Laplace 8-neighborhood transform yields better results than Laplace 4-neighborhood operator. The future work which can be worked upon this algorithm is the real-time monitoring and inspection of the surface defects in welded joints.

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