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# AUTOMATED SOLAR RADIO BURST DETECTION ON RADIO SPECTRUM: A REVIEW OF TECHNIQUES IN IMAGE PROCESSING

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## ABSTRACT

The information of solar atmosphere was obtained after investigating the recording radiation of the space mission. With technology growing recently, a lot of solar radio receiver was introduced to monitor the solar radio activity on the ground with high efficiency. It is recorded in every second for 24 hours per day. A massive of solar radio spectra data produced every day that makes it impossible to identify, whether the data contain burst or not. By doing manual detection, human effort and error become the issues when the solar astronomer needs the fast and accurate result. Recently, the success of various techniques in image processing to identify solar radio burst automatically was presented. This paper reviews previous technique in image processing. This discussion will help the solar astronomer to find the best technique in pre-processing before moving into the next stage for detection of solar radio burst.

**Keywords:** monitoring solar activity; automated solar radio burst detection; image processing; technique.

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## 1. INTRODUCTION

The solar radio emission has been an object of research since the first discovery in 1932 [1]. The investigation was studied systematically until now. The thermal radio emission of the Sun shows the useful knowledge about the physical state and transition process at the chromosphere, corona and active region (AR) of the sunspot [2-4]. Therefore, this investigation is a great contribution towards their impact on astronomy and terrestrial applications [5-6]. Moreover, space weather associated with sun environments. Based on the definition given by the US National Space Weather Program, the space weather is defined as the all condition on the Sun and in the solar wind, all of the atmospheres on Earth can influence the performance and reliability of the ground-based technology systems and affect human health. Thus, the human life is essential than others such as telecommunication system and spacecraft [7-9]. As known, sun always emits light and radiates the whole of the electromagnetic spectrum also energetic charged particles that can reach the earth within 8 minutes [10]. Moreover, the variability of the space weather [79] depends on the periodic and episodic of the sun [11].

The monitoring of solar activities within 24 hours all over the world becomes a reality when United Nations together with NASA start supports the developing countries to participate since 2007. Therefore, the research collaboration and program under ISWI (International Space Weather Initiative) have run across the world and it sponsored by SNF, SSAA, NASA, Institute for Astronomy and another private research center [12]. In this program, the whole process including the designing the instrument until presenting the result was done by the researcher. In South East Asian countries, for example Malaysia and Indonesia had started the research on solar radio astronomy since 2006 [13-14]. The program continued until now through collaborations with others international center such as ETH Zurich [15-16].

In the solar eruption observation, big solar flares were one of the causes of the earth disturbance and triggeredthe Coronal Mass Ejections (CMEs). The first observation and analysis of radio emission of solar flare haves been discussed nearly one century as written by [17]. This solar radio emission founded in two wavelengths: meter wavelength with five type [18] and decimeter wavelength in four types [19-20]. During a huge solar flare and CME occurs, the solar radio burst also produced. This burst was important as an initial sign of the huge eruption on the solar. It was discoveredwhen solar radio burst found to have related with huge solar flare and CMEs [21-24]. Furthermore, when solar flare in impulsive phase intense (X-ray) able to generate more radiation in meter wavelength and may have continuum [25-26]. The solar radio burst can be defined as solar emission in radio wavelength. Most of the radiation resulted from the unbalance activity at AR where it has strong magnetic field and hotter as compared with to surroundings. The details information about this formation was still in discussion and investigation due to its natural activity. Since the solar radio burst was randomly polarized, the suitable the antenna is needed to capture the total solar radio burst [27]. Telescopes can observe most of the incredible phenomenon from the outer space. There are a lot of telescopes were invented and able to observe in the wide range of electromagnetic spectrum [28-29]. Naturally, the solar radio signal is present in the low wavelength. Therefore, efficiency, sensitivity and size of radio telescopes [76-78] are very important to measure the radio emission. For radio telescope, there are two types of components which are an array of the radio antenna and a sensitive radio receiver [30]. In the spectrometer designing, the specific range frequency was the first things to choose and must focus on the research objective. For radioantenna, normally it designed in a large diameter size compared to the optical telescopes. Then, another important element in the antenna is the antenna radiation pattern where it received the signal. Hence, it was very sensitive to surrounding of the antenna location [31]. During the observation, noise or distortion is the major limitation of the instrument. The distortions are the human-generated interference need to be protected due to weak radio cosmic and easily change with the terrestrial radio signal. Therefore, the radio interference of the location observation must be identified earlier before the real radio emission observation [32-33]. Further explanation of this issue will be discussed later in this paper. The output of radio spectrometer was recorded in dynamic spectrograph [34-35]. The received signal was measured and converted into a different level of intensity on spectrograph for easy visualization. The details explanation of the solar radio spectrum will be discussed on the next topic.

Currently, most of the spectrometer can record the solar activity in 24 hours through the year.

With the production spectrum efficiency of the spectrometer, massive digital images can be produced. The efficient system needs to eliminate the non-quality image for better detection. Also, it became the biggest challenge in astronomical research. Therefore, many systems had been developed using the various method to help the researcher or user. The focus of this paper is to discuss and compare between the previous and current method in image processing for the solar radio burst automation detection on the spectrum. The image processing is one of the common methods used in the system. There are several stages in processing the solar radio spectrum data including the pre-processing, burst detection and classification type of burst. However, this paper only focused on the detection of solar radio burst the spectrum. The details explanation for each stage and method will be explained later.

## 2. METHODOLOGY

### 2.1. Dynamic spectrum

As mentioned before, the solar radio emission was recorded and converted into intensity or flux on the dynamic spectrum. All the data spectra were contained two (matrix of grey level images) or more dimensional (color images), but currently, most of the spectrometer [35-36] generate two dimensional which is intensity in frequency and time channel. Each intensity pair of the channel is called pixels. The frequency channel captured the radio signal at the same time. Hence it was assembled to form a solar radio spectrum. While, the time channel depends on the time solar radio recorded. An important component of time channel is time resolution, where the smallest value gives the better result. This is because time resolution is based on the average number of signal per one second, so that the increasing number of the column the more accurate of the received signal [37]. The intensity present in both channel also can be written in a row (N) and column (M) to form a final resolution spectrum (M X N). One of example original spectrum from Compound Astronomical Low cost Low frequency Instrument for Spectroscopy and Transportable Observatory (CALLISTO) are shown in Fig. 1. In science astronomy, data spectrum was formatted in Flexible Image Transport System (FITS). The file of FITS could be readable into many open sources such as C, C++, MATLAB [82] and others big name in programming languages [38]. The features of this format are easy to investigate because it writes in human-readable ASCII header. All the information is stored in that header. The intensity of the spectrum was rated from 0 into 255 [39-40]. The flux was the format in 10-bit ADC output. The intensity (digit) of spectrum can convert into intensity (dB) by using the following Y-factor r noise ratio burst equation [40]:

$$Y(dB)\frac{DigitHot - DigitCold}{DigitRange} - \frac{VoltRange}{g} = dB$$

where DigitHot: value of hot sky on spectrum, DigitCold : value of cold sky or quiet on spectrum, DigitRange: the ADC full-scale digits range for FITS files, VoltRange: the ADC full-scale voltage range and g: the log detector gradient.

From the literature review, the important characteristics of the spectrum were the number of the frequency channel, number of pixels, duration and time resolution [41-44]. This is because all the information is important to build the frame in the system.

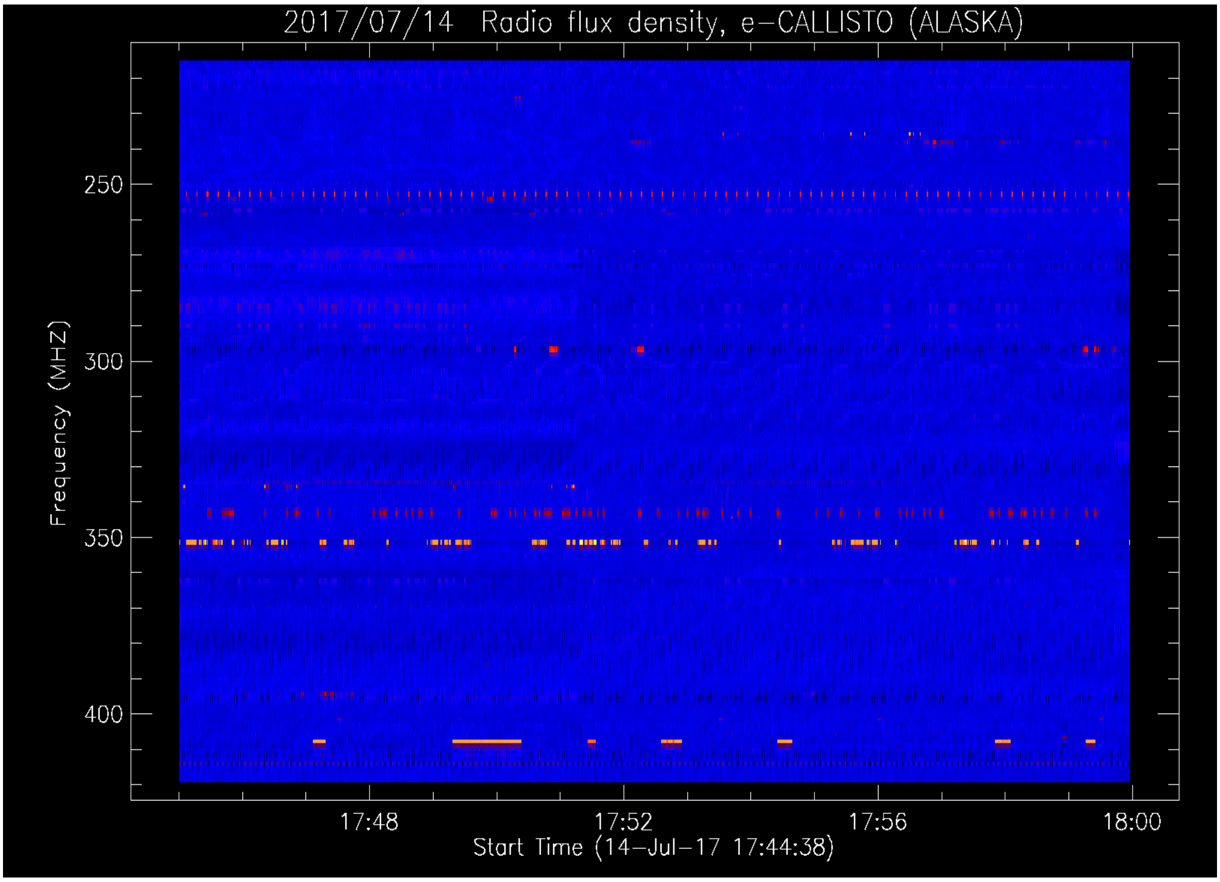


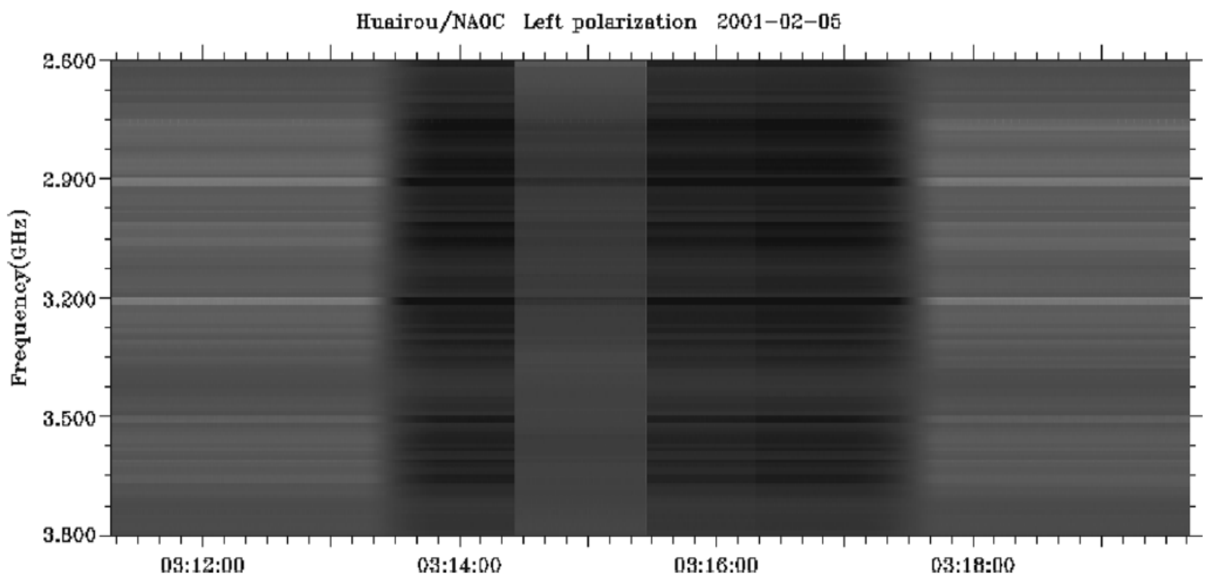

**Fig.1.** Examples original of CALLISTO spectrum from the station of Anchorage, Alaska Unites State America (USA) on 14th July 2017 (17:44 - 18:00UTC)

### 2.2. Pre-Processing

Pre-processing is the initial stage of the system, after received the output spectrum. At this stage, the cleaning process on the spectrum was occurred to get the clear spectrum for better burst detection. This process helps the researcher to determine, whether the solar burst appeared or not on the spectrum. Normally, the image processing took place in the first step. The elements involved were the intensity thresholding, filtering or normalization, down-sampling and enhancement of the spectrum. Before that, the details information of the dynamic spectrum must analyze first to avoid the mistaken mainframe of the system. This is because all the spectrometer has different instrument set-up which depends on the type of antenna, frequency needed and environment location.

**2.3. Image Processing**

Image processing is the process of manipulation intensity on the image using mathematical operations. Commonly this method is well-used in pre-processing of the system. In the original spectrum, there are a lot of distortions and solar burst was together recorded on the spectrum [45]. This is because the receiver or antenna at spectrometer was collected all the radio signal during solar radio observation. This issue was the main problem before it continues into the next stage. In addition, to recognize the sources and characteristics of the solar burst are not easily because [46] solar radio burst also can be found in one second with the drift of the frequency. However, in [47] claimed that noise or interference exists when it shows the same pattern in many times as shown in Fig. 2.



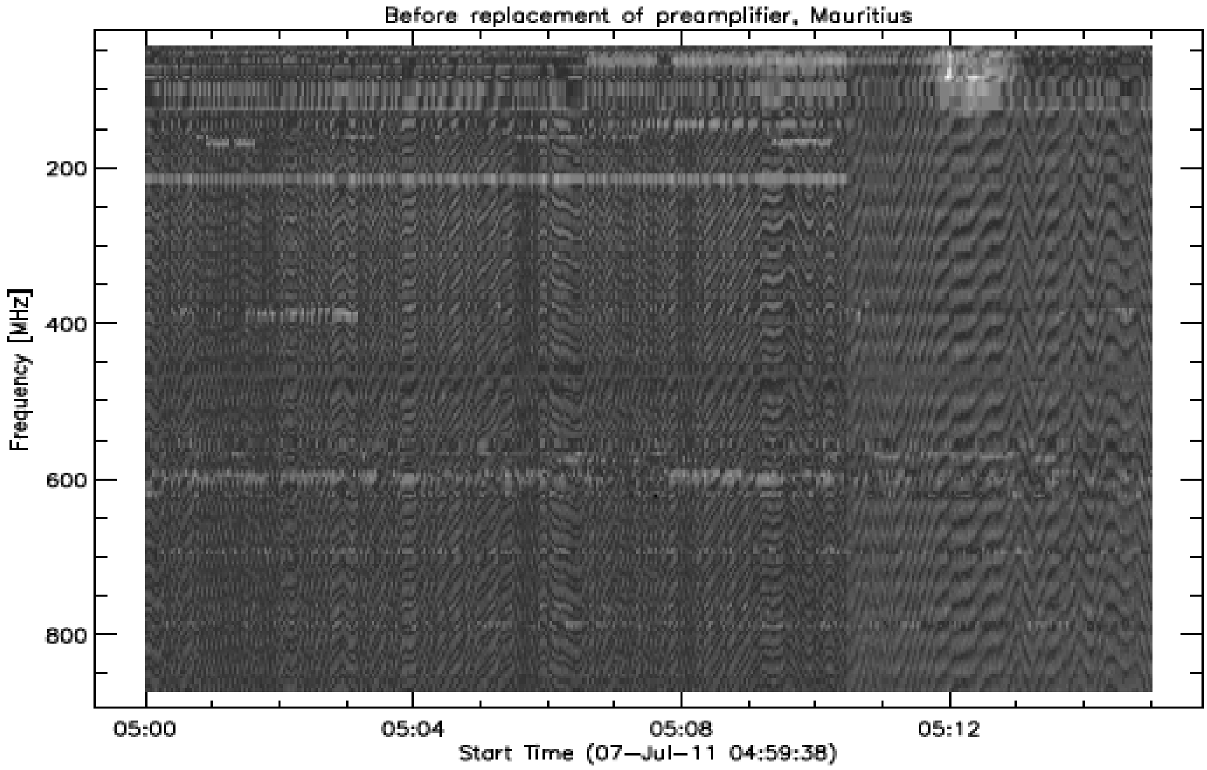



**Fig.2.** Several examples of spectrum that has interference due to instrument [34-35]

From the literature review, the important elements are intensity thresholding, denoising, filtering, enhancement and down-sampling are the top list. Later, it will explain details**.**

## 3. RESULTS AND DISCUSSION

### 3.1. Intensity Thresholding

The intensity thresholding was the local intensity distribution histogram found from the combination of intensity distributions on each the frequency channel [48-51]. This method was popular in many applications such as object tracking [52-53], vehicle surveillance systems [54-56], solar image [57-58], etc. As general, it was used to detect the changes between corresponding image [59]. The different features of the spectrum will be corresponding to the intensity distribution histogram. Hence, it can see through the observation done by [60] as illustrated in Fig. 3 when there is no coronal hole show on the solar radio spectrum; the unimodal distribution is formed. While, when there is a flare or burst appeared on the spectrum, the bimodal distribution shows the minimal boundary threshold. Then, the local histogram will be obtained after combining the minimum between two different features. However, to get accurate of local threshold point, the distribution histogram of the solar image must be conducted into several sub-images and then it will combine their threshold minima.

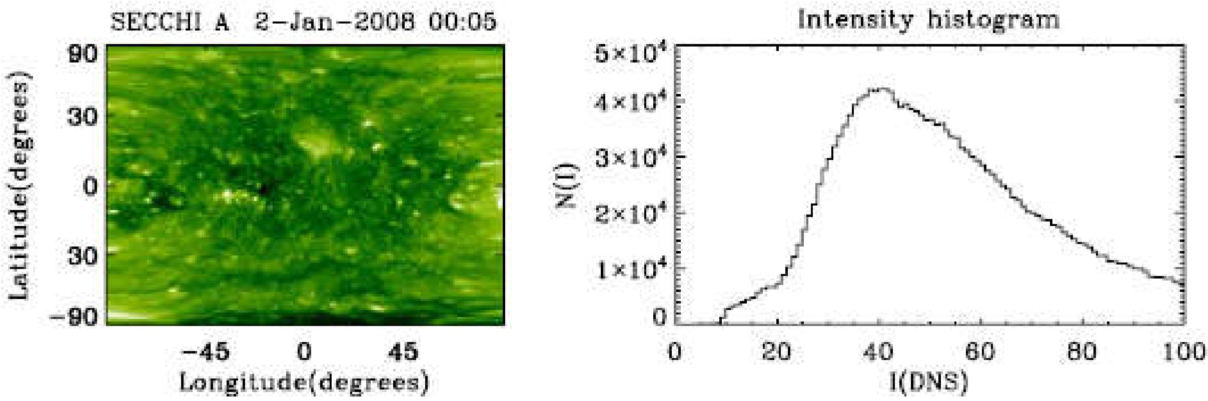



**Fig.3.** Left: The EUVI 195 Å LEAP image with no coronal hole formed, Right: The unimodal intensity distribution

Another function of this method was in image segmentation [59-60]. The original image can be dominant subject compared to the background intensity. In [61] applied the thresholding on within-class variance to classify spectrum as object and background of similar sizes. In addition, this method is only practical for the calibrated data due to more robust and simple technique [57]. However, the intensity thresholding has a lot of application when the image was the subject of the materials.

### 3.2. Denoising

Commonly, noise and blur were the two biggest problems for the image visualization. This problem is haunted the solar researcher during their initial filter. The definition of blur given by [62] is the image does not follow the Shannon-Nyquist sampling conditions [63], while noise is a constant intensity in frequency channel to give a high value of pixels in the spectrum. Most of the noise appeared in white color, which is affected the process of spectrum analyzing. Denoising is the process of elimination blur to make the free random fluctuation. There are a lot of type of image filterings such as variables methods (linear and nonlinear filtering), wavelet filtering and adaptive averaging filters and etc. [64-68]. But, in [64, 69] claimed that the best filter is a classic Gaussian filter. This filter must be repeated in every frequency channel because the antenna has different frequency value. The source of noise can be from the electric instrument such as microwave ovens, cordless phone and the wireless device. Another important parameter for noise is signal-to-noise ratio (SNR). It was to compare the ratio between the signal power and noise power. A good of standard image is about 60 dB. However, to separate the very fine of noise and solar radio burst which is formed in very smooth component was very challenging. In [64] state that, the requirement of denoising algorithm must considering the noise model and generic image smoothness model, local or global.

### 3.3. Filtering

Image filtering is another important element during pre-processing of solar radio burst detection because it can smooth the spectrum visualization and enhances the edges. It kind looks similar function with denoising but it was different. This is because the function of denoising is to remove the noise and recover the image. Whereas, filtering can apply any "filter" to an image but not all filtering is denoising. This process can be applied directly to the raw spectrum or after denoising of the pixels values. There are two basic filters, which are linear and nonlinear filter. The linear filter is used when the pixels in the original image are a linear combination. Otherwise, it was nonlinear. For solar radio burst spectrum, we have assumed that the received signal was linearly polarized. Hence, the linear filter was more suitable to imply such as a Gaussian filter in [53, 69, 71]. This filter is easy to understand and fast to compute. Therefore, most of the automation detection of solar radio burst is preferable to use this method. Meanwhile, the nonlinear filter is suitable for detecting the edges at all orientation simultaneously such as tracking solar activity on the spectrum [53, 70].

### 3.4. Normalization

After the fluctuation on the image has been removed, the interference on the signal still appeared as Fig. 2. It was still disturbing the presentation of solar burst on the spectrum. Hence the channel normalization will be applied [69, 72-73]. This process is also known as background cancellation. The basic equation of this method is:

$$S = \hat{S} - S_{LM} + S_{bck}$$

where $S$ is the output of normalization, $\hat{S}$ is input spectrum and $S_{LM}$ is local mean of the spectrum. While, $S_{bck}$ is the mean of the whole spectrum adds with the global background. The value of $S$ must in nonnegative time series [69, 71-73, 75]. Then, the decision threshold for the $S$is compared with a global mean of the whole spectrum. If exceeded the threshold, the noise or channel effect still appeared on the spectrum. The noise on the original spectrum able to reduce into less polluted with noise as Fig. 4.

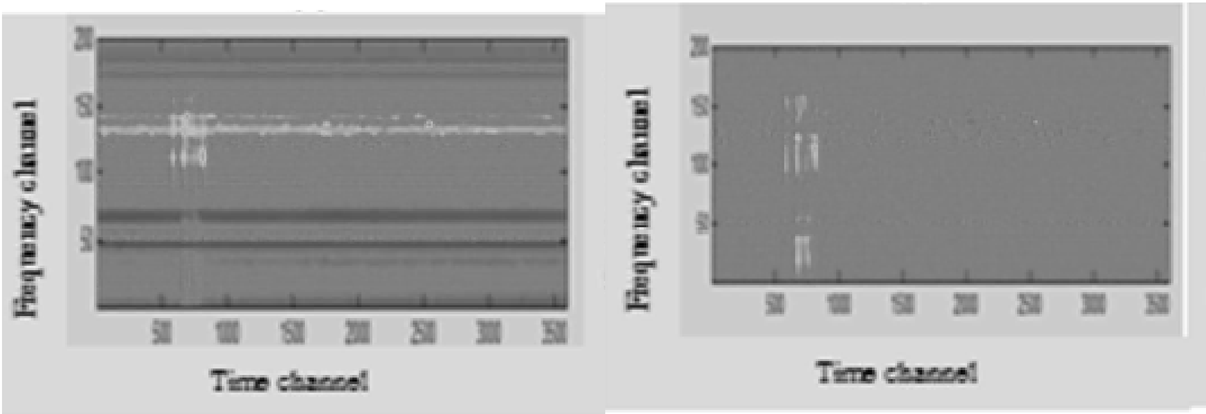
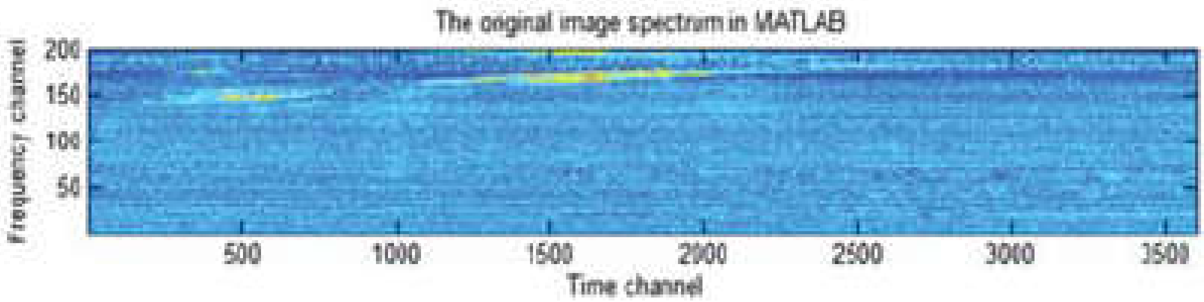



**Fig.4.** (Left) the original spectrum viewed using MATLAB, (right) the spectrum after channel normalization on 12th June 2014 from CALLISTO spectrometer [74]

### 3.5. Enhancement

Another famous element is enhancing the intensity of the image and needed the filter to implement. This process can increase the significant edge in the solar radio spectrum to help the expert in solar activity to distinguish between the important and meaningless images. As [44] states that the pixels are present the mean value in a Gaussian distribution. These variations are needed to handle well because all the value of the spectrum is the corresponding probability of the existence of burst. Image enhancement can be divided into two categories which are spatial domain and frequency domain methods. The spatial domain method is operating directly on the pixels while the frequency domain operates on the Fourier transform. In [72-73] used the grey-scale manipulation paper, in [53] used edges preserving smoothing and in [74] used the histogram equalization. Unfortunately, the best of the method in image enhancement was not decide because it depends on the user desired. Following are the example of the image enhancement process using neighborhood averaging in [75].



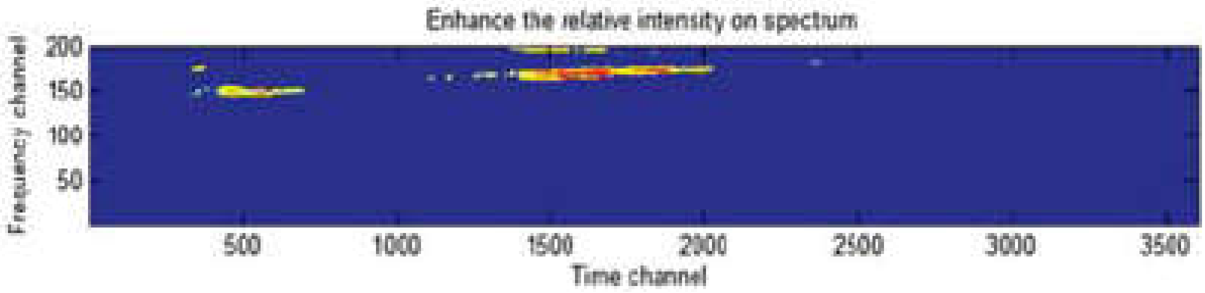



**Fig.5.** (a) The original spectrum viewed in MATLAB from CALLISTO station in Mauritius, (b) intensity of the spectrum was enhanced

### 3.6. Down-Sampling

After noise and channel effect are removed from the spectrum, the resolution output of the spectrum was still the same. Every spectrometer has different time recorded, which is make it different channel time. For example, in [34] produced 2520 x 120 while in [35] generate 3600 x 200 making the huge pixels in the result. Hence, the down-sampling the resolution of the spectrum is the best to apply because the example in [44] shows the correlation coefficient between frequency and time channel are not a significant difference. In addition, this procedure was suitable and needed before continuing the system as well as reducing the time scanning in next stage. In can be observed that in [75] also applied this method for rearranging the time channel according to the time resolution spectrometer.

## 4. CONCLUSION

We have described the important technique in image processing for the automation solar radio burst detection system on the solar radio spectrum. Although advance techniques were generatedin this day, the image processing was still used to recover the original of solar radio spectrum for better spectrum. The biggest issues in pre-processing of solar radio spectrum were the noise or distortion of the frequency channel. By using several techniques such as denoising, using the suitable filter as have been discussed before able get the best output spectrum. After eliminating the unwanted on the solar radio spectrum, the intensity of the spectrum needs to enhance to get the clear edges of the image. All the discussed technique was the initial step before the detection and classification of the solar radio spectrum. It was hoped that this review could use as the initial guide for all the researcher, especially in solar radio astronomy instrumentation to build their system.

## 5. ACKNOWLEDGEMENTS

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