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Huffman decoding performance analysis of lossy compressed LAPAN-A3/IPB multispectral images

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Abstract. LAPAN-A3/IPB multispectral imager has the ability to produce realtime acquisition images anywhere in the world as long as there is X-band receiver in ground station to receive the image data. The received image data is the compressed version of the original image data, compressed by lossy algorithm of Fast-Fourier Transform and Huffman encoding. Processing of the received image data can be considered complicated in terms of decompressed image data validity and processing time needed. This research aims to develop robust decoding algorithm for LAPAN-A3/IPB multispectral image received in realtime acquisition mode from Bogor ground station. The research focuses on developing efficient method on Huffman decoding for relatively big image data by using look-up-table approach. The developed decoding algorithm has successfully produced daily LAPAN-A3/IPB realtime images with good image quality, where the results have been validated by using original images, recorded on satellite memory. However, the time processing needed for processing any single image is still poor, where 1 GB of compressed image data needs around 1 hour of processing time. Therefore, although the algorithm has been used to regularly produce daily LAPAN-A3/IPB realtime image data, the faster algorithm is needed to achieve better overall processing performance.

1. Introduction

LAPAN-A3/IPB satellite is third Indonesian microsatellite which has remote sensing and maritime surveillance missions. To accomplish remote sensing mission, it has a pushbroom multispectral imager of red, green, blue and near-infrared (NIR) color channels with 15 meter resolution and 120 kilometer swath-width [1]. The imager has main feature to produce realtime acquisition images which is then transmitted by a 105 Mbps transmitter. With this feature, LAPAN-A3/IPB satellite could produce infinite worldwide acquisition as long as there is an X-band receiver in ground station to receive the transmitted image data. However since the imager has 8000 detectors for each color channel, where each detector produces 16 bit data, the imager produces 323.37 Mbps data rate for current imager setup of 1.9 ms repetition time, which exceeds the satellite transmission rate capability [2]. Therefore, the transmitted image data must be compressed either by lossless or lossy method [3,4]. In current setup, LAPAN-A3/IPB realtime multispectral image is compressed by using lossy approach, which consists of bit reduction, Fast-Fourier Transform (FFT) and Huffman encoding [4].

Encoding process of LAPAN-A3/IPB image lossy compression could be considered as trivial task, since neither of bit reduction, FFT algorithm and Huffman encoding is hard to implement in on-board Payload Data Handling System (PDHS) by using Field Programmable Gate Array (FPGA) [5,6]. In the other hand however, decompression process of the received compressed image is not trivial, either on software or hardware implementation. Bit reduction inverse problem which is bit multiplication by power of two definitely a trivial problem by just adding the data with several zero bits value. Inverse problem of FFT process can also be considered as trivial problem, since both encoding and decoding of FFT algorithm could be implemented by using a well-known butterfly diagram approach [7]. Huffman decoding by contrast, could not be executed in easy manner, both on software and hardware implementation. While Huffman encoding can be implemented by using simple and straightforward look-up table on PDHS of LAPAN-A3/IPB, Huffman decoding of the received image data on ground station is much harder to implement, especially in terms of processing time needed. Several detail researches related to Huffman decoding algorithm could be found on literature by using bit-by-bit approach by using encoder look-up table [8,9]. Another algorithms by using modified look-up table can also be used to solve Huffman decoding problem [10,11]. Each approach has its own advantages and disadvantages, both in terms of coding complexity and processing time needed.

This research aims to develop Huffman decoding algorithm which will be used to process realtime acquisition images of LAPAN-A3/IPB multispectral imager. The developed algorithm uses modified look-up table approach in favor of commonly bit-by-bit approach, to minimize the processing time needed. In general, the algorithm will produce several decoded pixel values for each use of look-up table, which in turn will speed-up overall decoding process. The developed decoding algorithm is evaluated by using several realtime acquisition of LAPAN-A3/IPB multispectral images, in terms of processing time needed as well as accuracy of the resulted decompressed images compare to the corresponding original images from recorded satellite mode. This research uses processing time needed for overall decoding process as main performance evaluation, since processing time is the most constraining aspect for most of Huffman decoding algorithm.

This paper is organized as follows. Section II gives brief description of research methodology and Huffman decoding algorithm which is developed in this research. Section III discusses some results and analysis of decoding process of LAPAN-A3/IPB realtime multispectral images by using the developed algorithm. Finally, section IV gives some conclusions of this research along with some recommendation for future works related to Huffman decoding algorithm.

2. Methodology

As already mentioned earlier, this research will develop Huffman decoding algorithm to process LAPAN-A3/IPB realtime acquisition images. In general, this research consists of several stages, starting by reviewing image compression algorithm of LAPAN-A3/IPB multispectral images as well as theoretical Huffman decoding algorithm. Next, Huffman decoding algorithm based on modified look-up table is developed for software implementation, and then followed by several performance evaluations of the developed algorithm. Processing time needed to process LAPAN-A3/IPB images captured during realtime acquisition mode is heavily analyzed, while the accuracy of the developed algorithm is conducted by comparing the decompressed images to their corresponding uncompressed images. Last but not least, several potential aspects are discussed in order to improve the performance of the developed algorithm in the future. Figure 1 show general flowchart used in this research.

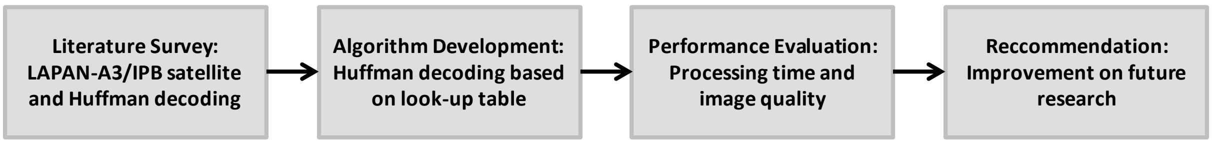


Figure 1. General flowchart of this research.

In the developed LAPAN-A3/IPB multispectral image decompression algorithm, the received compressed image is decoded by using several stages of data processing. Initially, binary raw data is processed based on Consultative Committee for Space Data System (CCSDS) format to produce raw compressed image data and satellite metadata. Next, raw compressed image is decoded by using

Huffman decoding algorithm first, and then followed by inverse FFT processing. Since the received compressed data commonly has about 3 GB size, which equivalent to roughly 10 GB decompressed image size, the algorithm also consists of memory allocation management which divided the received data into several smaller data in order to avoid computer memory limitation problem. Figure 2 shows general flowchart of LAPAN-A3/IPB multispectral image decompression algorithm.

Figure 2. Image decompression algorithm of LAPAN-A3/IPB realtime multispectral images.

Huffman decoding algorithm based on modified look-up table approach which is developed in this research could be further divided into several stages of computation. First and most important stage, the look-up table must be calculated solely from original look-up table used for encoding process. This step is not necessary for bit-by-bit decoding approach since it uses exactly the same as original look-up table as encoding process. While original look-up table only consists of 512 entries of pixel coefficient value and their corresponding coded bits, look-up table which is used on the developed decoding algorithm consists of 32768 entries of decimal values of the received bits and their corresponding pixel coefficient values. Although the process of determining the transformed look-up table is not easy nor fast to execute, it only needs to be done once in a lifetime for each of the original look-up table which is used for encoding process.

To construct a new transformed look-up table which will be used in the algorithm, all decoding output possibilities from 15 bit input are tabulated, which in this case there are 32768 possibilities. Then each possible combination of 15 bit input is decoded by using ordinary bit-by-bit Huffman decoding approach. Each bit combination will produce at least one decoded values, or several decoded values for input entries which consist of several high probability occurrence values such as zero decoded values. Each input bit combination entry also has a value index to indicate number of input bits which are successfully decoded, to tell the algorithm to move forward for certain number of bits for a next 15 input bit decoding.

The actual Huffman decoding process then uses this transformed look-up table to process the received data bits. Since the look-up table consists of 32768 entries, it can handle 15 bits of received data stream at once, thus could produce several decoded values as output. In contrast, in bit-by-bit decoding approach, each bit of the received data bit stream is evaluated based on original look-up table of 512 entries. This approach is quite straightforward and do not need a lot of memory for 512 entries of original look-up table, but the need of evaluating the data stream in bit by bit basis could produces significant delay of decoding process. Figure 3 shows flowchart of Huffman decoding algorithm based on modified look-up table which is developed in this research.

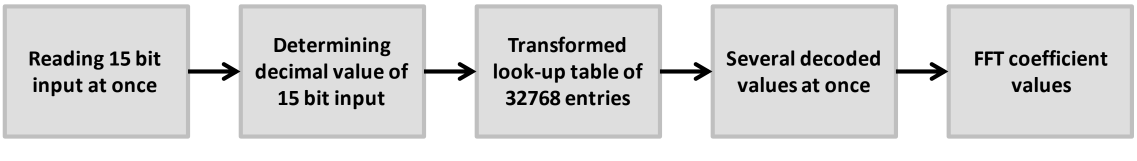


Figure 3. The developed Huffman decoding algorithm based on modified look-up table.

3. Results and Analysis

The developed Huffman decoding algorithm by using modified look-up table has been evaluated based on numerous images of LAPAN-A3/IPB multispectral imager which was taken under satellite realtime operation mode. Performance of the developed algorithm is evaluated both in terms of the resulted decompressed image quality and processing time needed.

3.1. LAPAN-A3/IPB Realtime Acquisition Mode

Since January 2018, LAPAN-A3/IPB satellite has been producing realtime acquisition images at least once a day for western Indonesia region. The realtime images are received from X-band receiver on Rancabungur ground station. This satellites realtime observation produces images from Aceh on the west to Kupang on the east, and from part of Thailand and Philippines on the north to Indian Ocean and part of north-western Australia on the south. Figure 4 shows mosaic images of LAPAN-A3/IPB multispectral images taken by using satellite realtime acquisition mode.

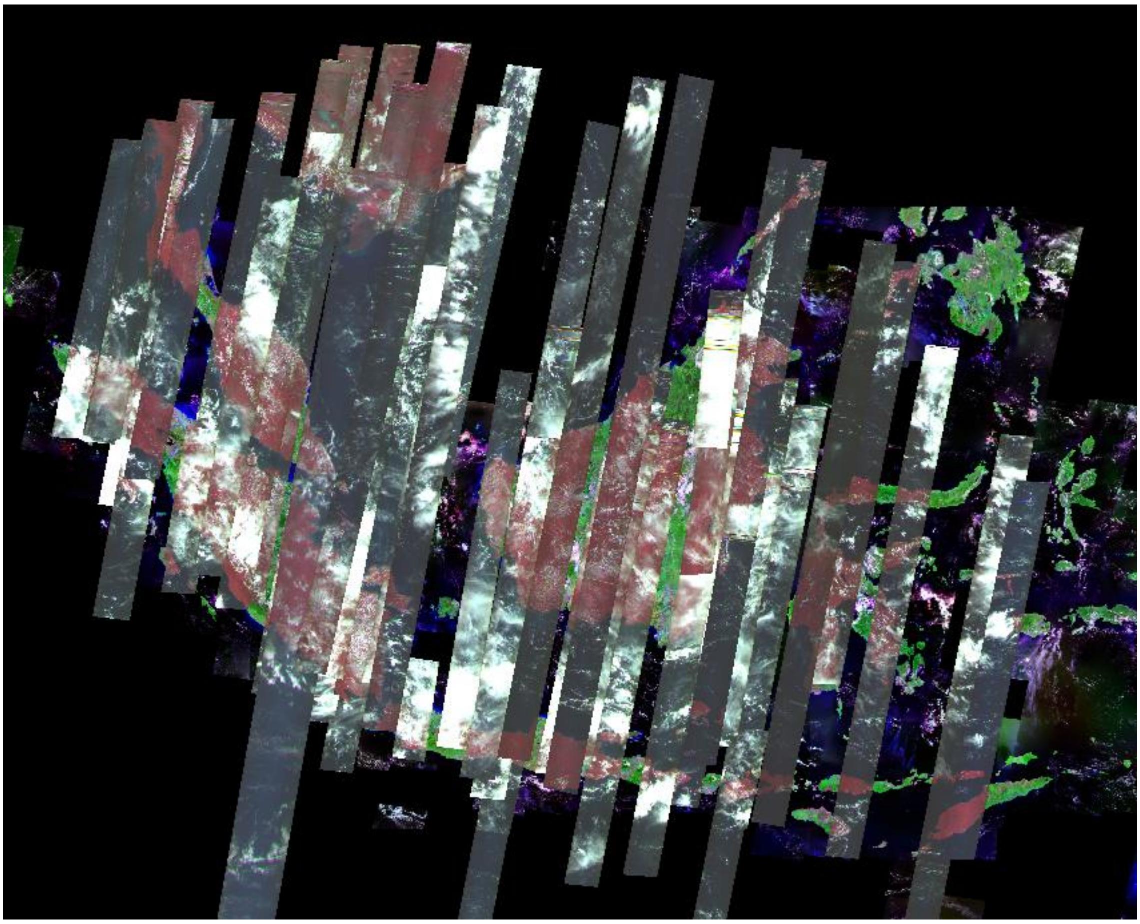
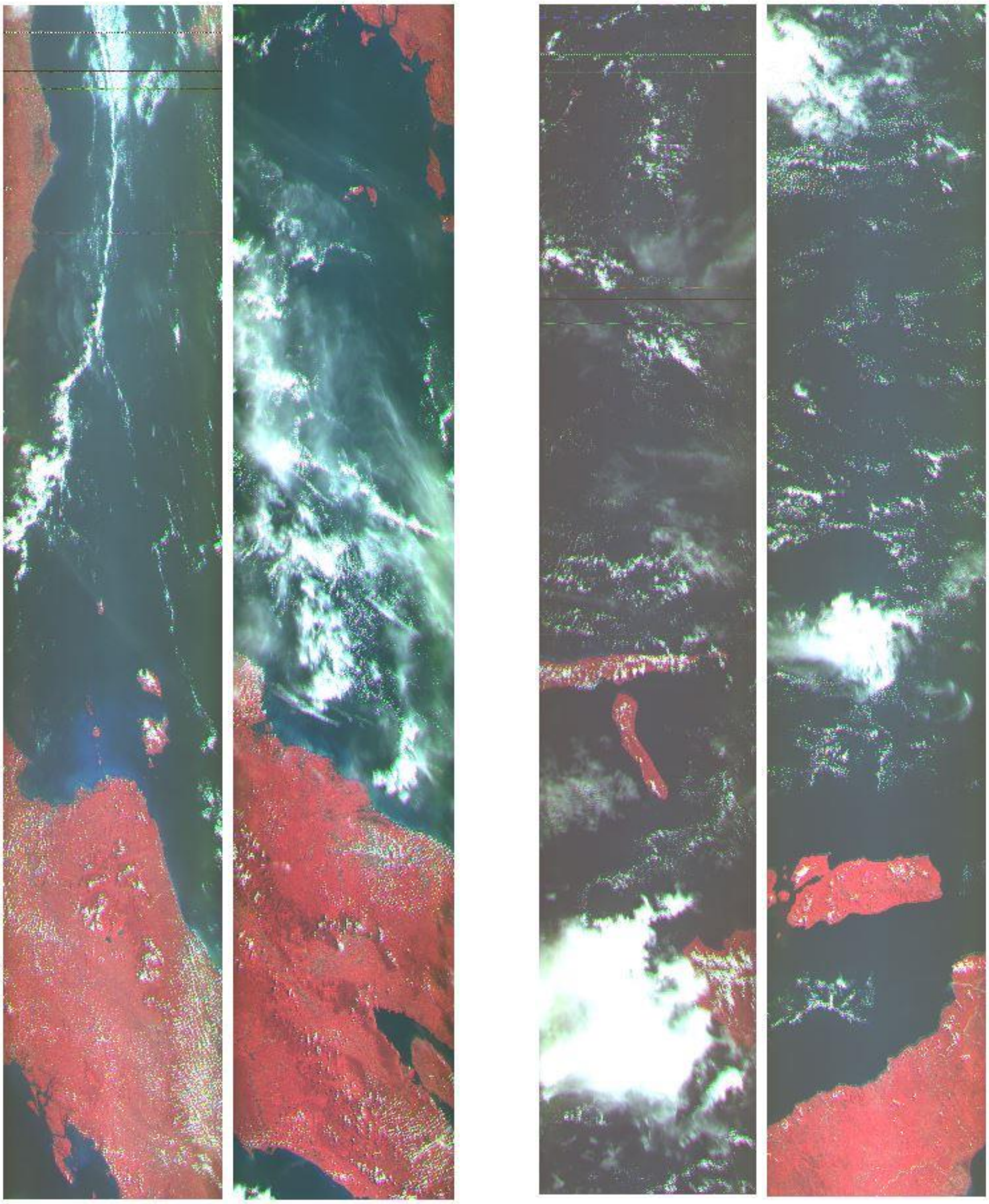


Figure 4. Mosaic of LAPAN-A3/IPB multispectral images on realtime acquisition operation.

3.2. LAPAN-A3/IPB Multispectral Image Decompression Results

In order to evaluate performance of the developed Huffman decoding algorithm, or LAPAN-A3/IPB image decompression algorithm in general, several samples of realtime acquisition image data are used. In average the received compressed data for each observation is 2-3 GB data size, or equivalent to around 4 minutes observation for approximately 1800 km image length. In rare cases where the satellite observes for longer observation period, each of the received compressed data could have about 4 GB data size, approximately 2800 km image length from 6 minutes of observation. The size of the received data could be even larger if the satellite continues to observe Indian Ocean in the south of Indonesia, however this is not the case on LAPAN-A3/IPB satellite operation.

Figure 5 shows examples of two decompressed images, where first image was taken when satellite passed over Thailand to North Sumatera while second image was taken when the satellite passed over Maluku to Kupang. Note that the decompressed images are divided into two parts each due to aspect ratio of image length to image swath-width are too big thus cannot be visualized properly if the images are not divided. The images are still in raw image form, thus have not been corrected systematically both geometry and radiometrically, nor have been spatial georeferenced.



(a) (b)

Figure 5. Decompressed images of LAPAN-A3/IPB multispectral imager on realtime acquisition operation, (a) Thailand-Medan observation, (b) Maluku-Kupang observation.

Based on the resulted decompressed images, it is found that in average, the compression ratio produced is about 3:1, where typical 2 GB of the received compressed image will be decompressed into 6 GB uncompressed image. It is also found that maximum decompressed image size produced is about 12 GB, produced from 4 GB of the received compressed image. Several of these decompressed images have been validated by comparing the images to their corresponding original images, which was stored into satellite on-board memory. However, due to limitation of satellite memory capacity, the original version of the images could only have maximum of 4 GB data size. Based on several images which have been compared, the resulted 12-bit decompressed images are highly similar to their 16-bit original version images, both visually and similarity of pixel digital number.

3.3. Image Decompression Processing Time

As already mentioned earlier, LAPAN-A3/IPB image decompression algorithm consists of several stages of data processing, which are CCSDS de-formatting, Huffman decoding, inverse FFT coding, and also input-output data streaming, such as reading binary data from raw data and writing binary data to the resulted decompressed image data. To further analyze the performance of overall image decompression algorithm, processing time needed to process several compressed images is analyzed. Table 1 shows the processing time needed to process the received compressed images data, divided into several above-mentioned stages of data processing.

Table 1. Processing time of LAPAN-A3/IPB multispectral image decompression

Processing Stage	Medan	Semarang	Makassar	Kupang
The compressed data	2.12 GB	4.01 GB	3.40 GB	2.21 GB
The decompressed image data	6.07 GB	11.50 GB	9.77 GB	6.35 GB
CCSDS de-formatting	375 sec	673 sec	568 sec	348 sec
Huffman decoding	7622 sec	13562 sec	9740 sec	7312 sec
Inverse FFT coding	112 sec	213 sec	177 sec	116 sec
Input-output data streaming	233 sec	398 sec	383 sec	200 sec
Overall Processing Time	**8343 sec**	**14846 sec**	**10868 sec**	**7976 sec**
Processing Time/GB raw data	**65 min**	**61 min**	**52 min**	**59 min**

Based on several image decompression results above, it can be seen that in average, processing time needed to process 1 GB of the received compressed images is around 1 hour. Therefore, typical raw data received with 2 GB data size needs about 2 hours processing time, which can be considered as moderate performance. It can also be seen from the table that, most of processing time needed is spent to execute Huffman decoding algorithm, which is almost 90 percent of the overall time spent. Processing time needed for other stages of processing such as CCSDS de-formatting and inverse FFT coding can be neglected, while input-output data streaming processing time have dependencies to network and storage performance at the time the processing took place.

3.4. Line Loss Influences on Compression Performance

As can be seen in figure 5, there are several line errors on the decompressed images. These errors can be caused by several reasons, such as when the data transmission were conducted in earlier or later stage of satellite contact duration to ground station, or when signal interference exists near the ground station which interferes LAPAN-A3 data transmission. Any of these reasons might cause the distortion on the transmitted data, where could cause several types of error. Relatively small distortion will cause several line errors in terms of false digital number reconstructed from decompression process. This happens since Huffman decoding algorithm is prone to bit error, where even one bit error could propagate to the rest of the decompressed digital number values. Fortunately, image compression employed on LAPAN-

A3/IPB satellite works on line-by-line basis, meaning that error occurs on one particular line will have no influence to other lines.

While relatively small distortion on the transmitted data causes line errors on the decompressed image in terms of random digital number values produced, relatively bigger distortion on the transmitted data might cause entirely loss of several image lines. This happens when the codeword of several image lines are distorted thus cannot be found from the distorted transmitted data. Even when entire data of one particular line is not distorted, but when the codeword of the line is distorted, then this particular line automatically discarded by the decompression algorithm. The example of this line loss error can be seen on figure 4, where on the first three months of realtime acquisition mode of operation, LAPAN-A3/IPB satellite failed to produce realtime images from northern Kalimantan. Investigated which has been done shows that there was X-band signal interferences near Rancabungur ground station on approximately 30-40 degree azimuth and 5-15 degree elevation angle, which causes the satellite could not transmit data perfectly from northern part of Kalimantan. This problem was then solved by conducting coordination with Ministry of Communication and Information Technology to eliminate the source of signal interferences near Rancabungur ground station.

4. Conclusions

LAPAN-A3/IPB satellite has a feature to execute realtime observation using multispectral imager and could produce theoretically infinite captured image. The images produced are compressed by using lossy algorithm of combined Fast-Fourier Transform and Huffman encoding. This research develops image decompression algorithm to process the received compressed image data from the satellite, focusing on efficient Huffman decoding by using modified look-up table approach. The developed algorithm has been validated by using numerous actual LAPAN-A3/IPB realtime multispectral images, and the algorithm successfully produces the decompressed images with good quality, compare to original version of the images which came from satellite on-board memory. The processing time needed to process 1 GB of compressed data is about 1 hour, producing about 3 GB of decompressed image. Since almost 90 percent of the time needed is spent to execute Huffman decoding algorithm, it is recommended to further improve the algorithm of Huffman decoding in the future. Hardware implementation of the image decompression algorithm should also be developed to be able to realize near-realtime image decompression processing for quicklook application.

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