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Improved object recognition performance of UWB radar according to different window functions

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Abstract

In this paper, we implemented an Ultra-Wideband radar system using Stripmap Synthetic Apertrure Radar algorithm to recognize objects inside a box. Different window functions such as Hanning, Hamming, Kaiser, and Taylor functions to improve image recognition performance are applied and implemented to radar system. The Ultra-Wideband radar system with 3.1~4.8 GHz broadband and UWB antenna were implemented to recognize the conductor plate located inside 1m3 box. To obtain the image, we use the propagation data in the time domain according to the 1m movement distance and use the Range Doppler algorithm. The effect of different window functions to improve the recognition performance of the image are analyzed. From the compared results, we confirmed that the Kaiser window function can obtain a relatively good image.

Key words : Stripmap, Synthetic Aperture Radar, Window function, Ultra-Wideband, Range Doppler

Ⅰ. INTRODUCTION

Recently, applications of radar are useful for short-range applications such as breast cancer detection, security applications, ground penetration or structural inspection as well as satellite or remote applications [1-5]. Because of the need to detect very small objects or defects, the ultra-shortband pulse characteristics of Ultra-Wideband (UWB) radar can handle millimeter resolution in centimeters[6-7]. UWB radar gives the high accuracy in material penetration ability and easier to separate objects.

In this study, a nano-second pulse width transmission waveform was implemented using Synthetic Aperture Radar (SAR) imaging technique to detect objects inside the box. In order to increase the efficient of radar performance in object detection, various smoothing windows were applied in time domain. For signal processing, MATLAB program was implemented to raw radar data collection and SAR image algorithm processing. The experiment is performed in lab environment with various background noise to confirm the ability of window functions in reduce interference and improve the performance of object detection from UWB radar. This work is organized as following: Chapter 2 gives basic theory and information about UWB radar imaging, type of window functions applied in experiment and SAR image algorithm, Range Doppler Algorithm(RDA). Chapter 3 shows how experiment

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set up, our journal to deal with this problem, the results with comparison and discussion. Finally, conclusion and future works to improve system is shown in chapter 4.

II. IMAGING METHOD

2-1. Ultra-Wideband Radar Imaging

The UWB is the radio technology with very low transmitted energy to use in short range communication. Conventionally, there are 3 ways to obtains signals from the targets by a radar system: monostatic[8], bistatic[9], multistatic[10]. This study used a monostatic approach to the PulsOn 440 device from Humatics Co. The PulsOn 440 unit operates a bistatic mode with a monostatic system with two closed antennas. The basic physical principle of the operation system is simple and displayed in Fig. 1. When the transmitted short pulse signal meets the target and cause reflection. The reflected signal from target is received by receiver and sent to controller computer. To obtain more information from the target, the radar is moved across on azimuth direction. The process of transmitted and received signal is repeated on each point on moving path. In SAR algorithm, the resolution of image which is the ability to detect 2 different objects in range and azimuth direction are calculated by Eqs. (1)-(2), respectively.

$$\Delta_r = \frac{c}{2B} \quad (1)$$

$$\Delta_{az} = \frac{\lambda R}{2^* SA} \quad (2)$$

Where c is velocity of light in the air, B is the transmitted frequency bandwidth, R is distance between center of radar movement aperture SA to the center of scanned area.

By using PulsOn 440 device, the transmitted pulse is operated at nominal Pulse Repetition Interval (PRI) 100ns with pulse width is 2ns as Fig. 2[11]. The power delivered to transmitted port can be configured and adjust as much as 30dB.

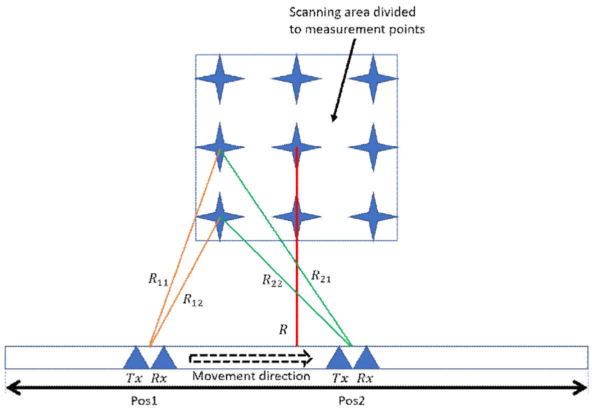


Fig. 1. Measurement principle of system.

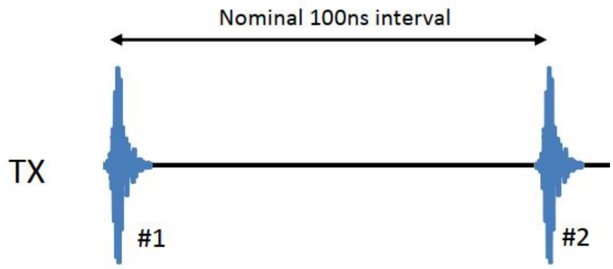


Fig. 2. Transmitted pulse of P440 radar device.

2-2. Window functions

In receiver antenna, the signals includes various reflected echoes as response from target, reflection from floor with so much noise and interference. The original received signal is shown in Fig. 3, the target is difficult to detect.

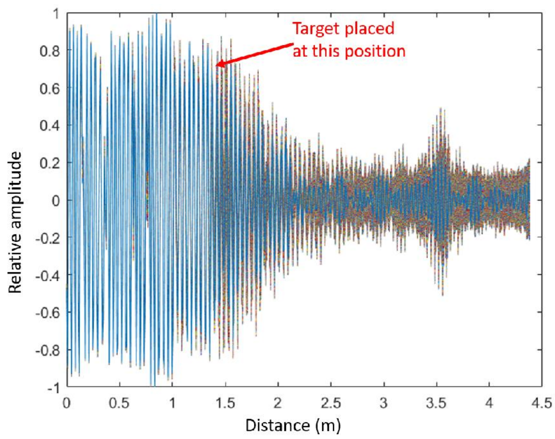


Fig. 3. Original waveform recorded from radar device.

In SAR technique, window functions are smoothing windows which is a real-valued function that rolls off symmetrically from its central peak towards the two end [12]. In case of multi-target, the large Radar Cross Section (RCS) target response can overcast smaller RCS, so window functions help to reduce the side effect from sidelobes. Some general smoothing windows in time domain are illustrated in this study. The rectangular window function at each element n with length L of signal is expressed as (3):

$$w(n) = 1 \tag{3}$$

Another window is Hamming with window shape is expressed by (4):

$$w(n) = \begin{cases} 0.54 - 0.46\cos\left(\frac{2\pi n}{L}\right), & 0 < n < L \\ 0, & otherwise \end{cases} \tag{4}$$

And the Hanning window is have same shape with Hamming window but it will touch 0 at both ends:

$$w(n) = \begin{cases} 0.5 - 0.5\cos\left(\frac{2\pi n}{L}\right), & 0 < n < L \\ 0, & otherwise \end{cases} \tag{5}$$

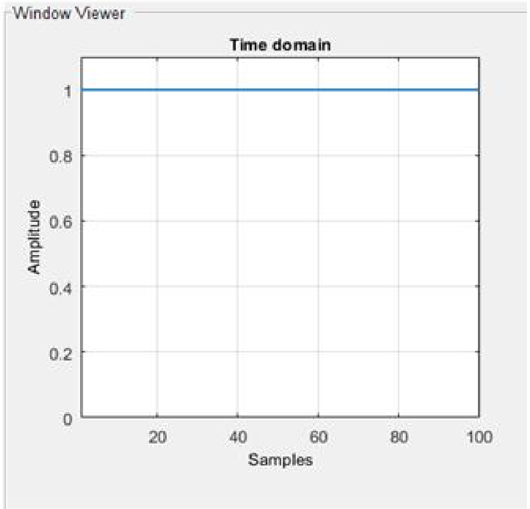
The Blackman window function is given by:

$$w(n) = a_0 - a_1\cos\left(\frac{2\pi n}{L}\right) + a_2\cos\left(\frac{4\pi n}{L}\right) \tag{6}$$

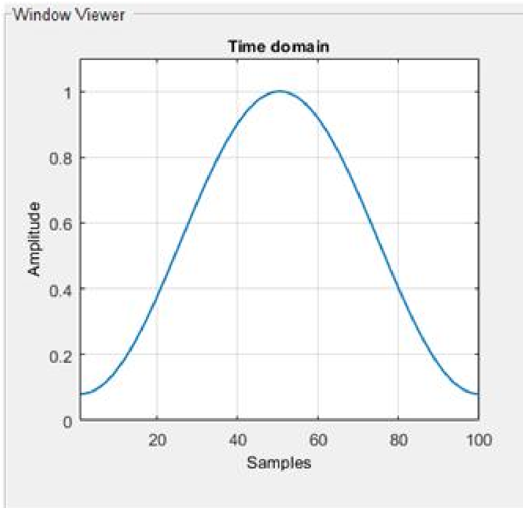
where $a_0 \approx 0.42, a_1 \approx 0.5, a_2 \approx 0.08$ [13]. The last general smoothing window introduced in this paper is Kaiser window which can adjust the roll-off of sidelobes by smoothing coefficient in (7):

$$w(n) = \frac{I_0\left(\beta\sqrt{1-\left(\frac{2n}{L}\right)^2}\right)}{I_0(\beta)} \tag{7}$$

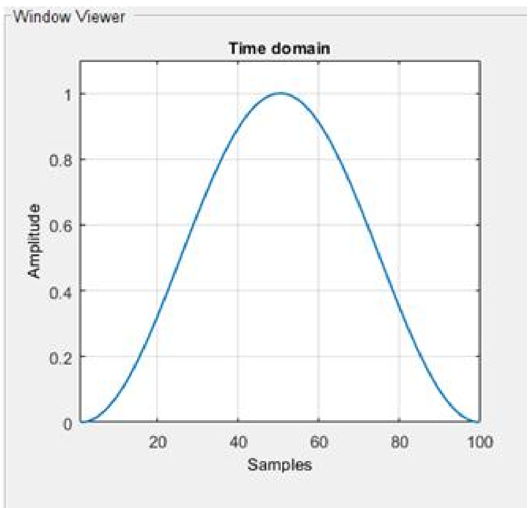
where β is smoothing coefficient and Io(.) is the zeroth-order of Bessel function [14]. The shape of each window in time domain is displayed in Fig. 4 with length L is 100 coded by MATLAB.



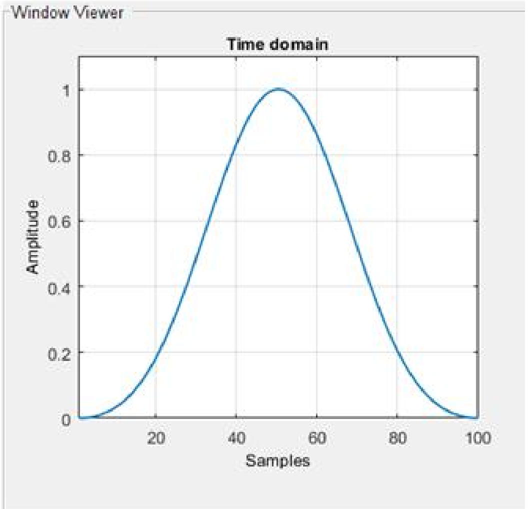
(a) Rectangle window



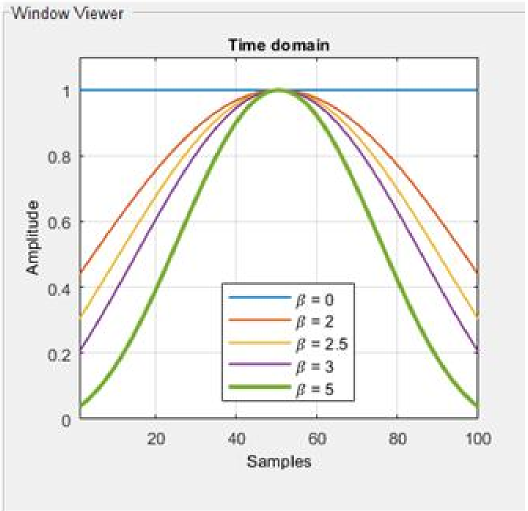
(b) Hamming window



(c) Hanning window



(d) Blackman window



(e) Kaiser window

Fig. 4. Smoothing windows in time domain.

2-3. Range Doppler Algorithm

Range Dopper Algorithm (RDA) is a basic algorithm to reproduce SAR image. The collected signal from receiver antenna is processed to raw data which is the input of algorithm. The basic RDA is implemented in this paper with the block diagram as Fig. 5. The main functions of basic RDA are Range Compression, Range Cell Migration Correction (RCMC) and Azimuth Compression. Firstly, the raw radar data is used to perform range compression where a fast convolution is done for the data in the azimuth time domain. After that, an azimuth FFT is executed to transform data to the range doppler domain. When the data is in range doppler domain, RCMC process is performed. This process is very efficient with multiple target to put them in exact position in the same frequency samples [12]. Then azimuth matched filtering is applied to focus the data in the azimuth direction. Finally, azimuth IFFT is executed to convert the data back to the time domain and show the result at single look complex(SLC) image.

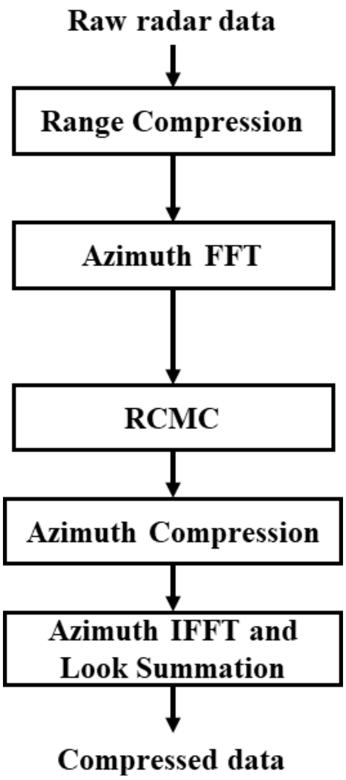


Fig. 5. RDA block flow chart.

III. MEASUREMENT RESULTS

3-1. Experimental setup

In the experiment, we used UWB radar devices provided by Humantics co. The devices can communicate with computer by internet or serial port. Fig. 6 shows the image of the device with 2 antenna ports, internet port or serial communication through USB port. This radar device transmits 2.2 GHz bandwidth at 4.3 GHz center frequency with pulse width is 2ns in an interval of each 100ns. As mentioned above in Eqs. (1)-(2), the resolution of SAR image from P440 device can be as in Table. 1.

Fig. 6. P440 UWB radar device.

Table 1. P440 radar device and experiment parameters.

Parameters	Value	Unit
Center Frequency	4.3	GHz
Frequency Bandwidth	2.2	GHz
Pulse Width	2	ns
Pulse Repetition Frequency	100	ns
Slant range of scene center	1.5	m
Synthetic Aperture length	1	m
Transmitted power	2.05	dBm
Range Resolution	6.82	cm
Azimuth Resolution	3-5	cm

In order to improve the efficient of system, we used directional UWB antennas as shown Fig. 7.

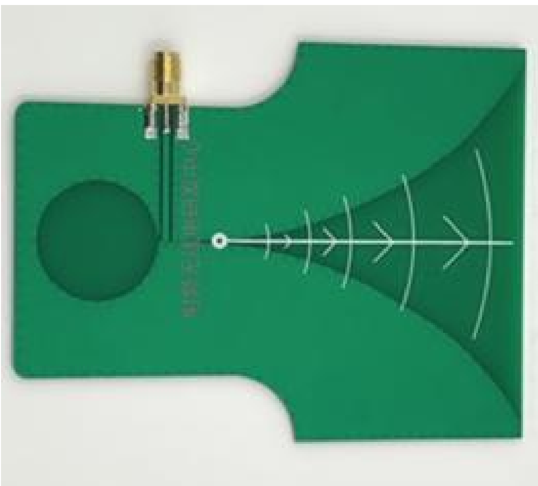


Fig. 7. UWB directional high gain broad band TEM antenna.

They are UWB directional high gain broad band Transverse Electromagnetic (TEM) antenna with frequency range 2.4~10.5 GHz, power capacity is 8W and antenna gain is 7dBi.

A movement assembly is designed to support moving radar as Fig. 8. We designed its with moving length in 0~1m and 2 modes of movement: stepped and continuous. This is connected and controlled by computer through serial port.

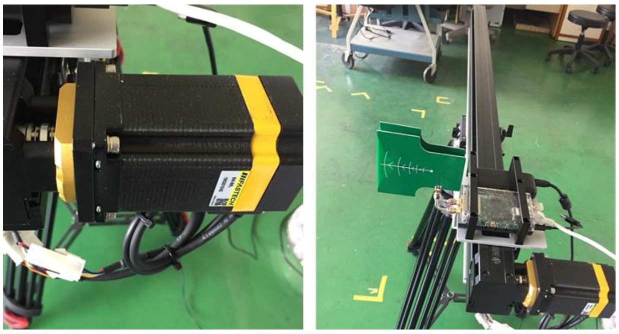


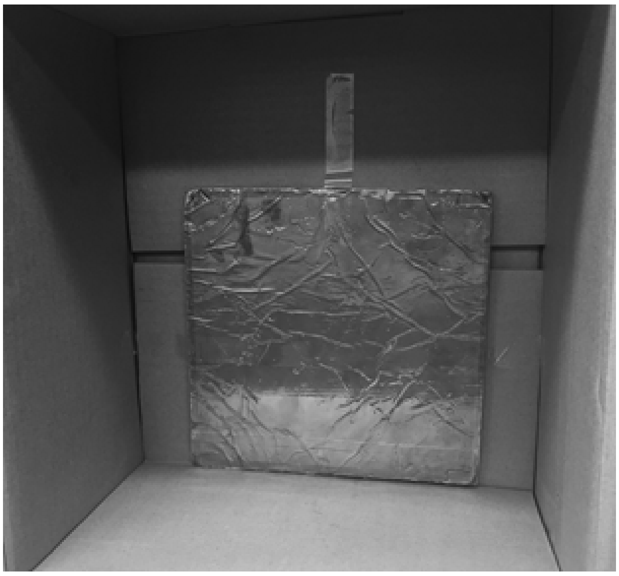
Fig. 8. Movement assembly support to move radar on azimuth path.

The imaging is programmed by MATLAB with functions to control movement assembly, radar, record and process signal with final step is image reproduction by RDA. In order to remove background noise and crosstalk signal of radar, calibrate the mean value with smoothing window is applied. To get the image, we controlled the movement assembly to move continuously in 1m of azimuth path with velocity is 5mm/s. While moving, the radar recorded data as fast as possible and in this case, we got total 3306 record for each scan process.

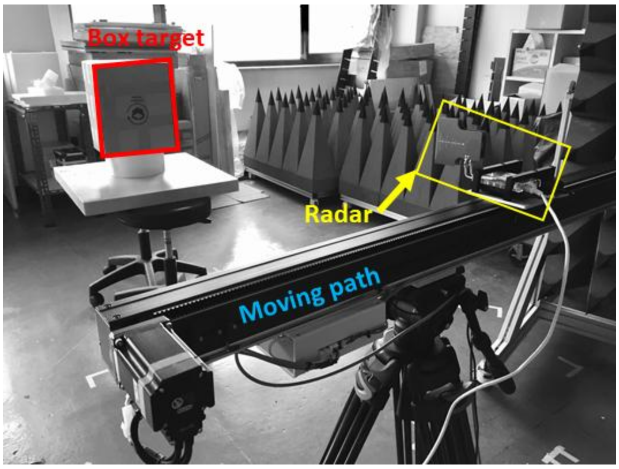
3-2. Experimental result

The target used in this experiment is a copper plate and put inside of a carton box to determine the ability to see object in where human eyes cannot see. The size of the conductor plate is 20cm×20cm, and it is located in a box which height, width and depth are 29cm, 35cm and 18cm, respectively. Fig. 9-a is the copper plate in the box and Fig. 9-b is the lab environment where simulated the experiment with various background noise can affect to the radar signal while the carton box without copper plate signal and image is shown in Fig. 10. In order to confirm the ability of UWB radar in see through object, we compared the image between box with and without copper plate. Different smoothing windows are applied in signal processing. From Fig. 11 to Fig. 15 are the signal after processing and the image of copper plate inside the box by applying Square, Hamming, Hanning, Blackman and Kaiser smoothing window, respectively.

Compare to Fig. 3 of original signal, windows functions with calibration process could help to display object more clearly by removing background and initialization noise.



(a) Target



(b) Experiment environment

Fig. 9. Target and experiment environment

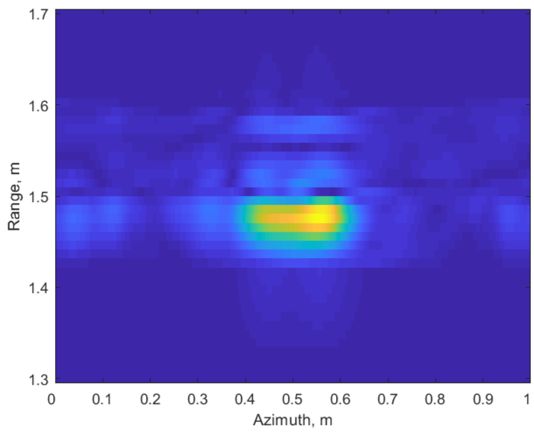


Fig. 11. Image reproduced by Rectangle window.

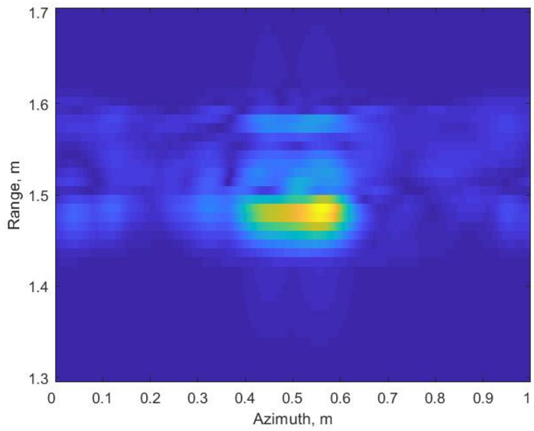


Fig. 12. Image reproduced by Hamming window.

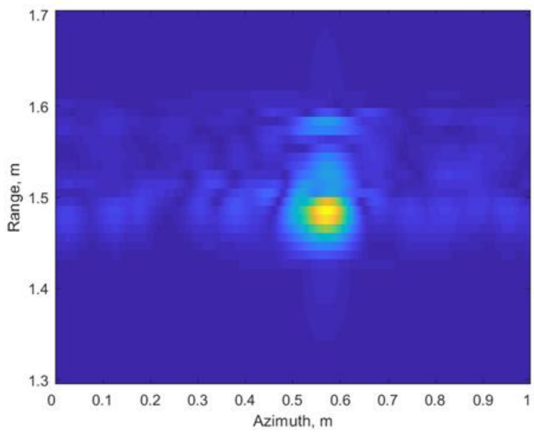


Fig. 13. Image reproduced by Hanning window.

As we can see in the result, the Hanning and Blackman windows give signal is clear with target but when apply in image processing step, it make the result is different and not good compare to Square, Hamming or Kaiser windows. By the results from experiment, Kaiser window shows a better performance in image reproduction.

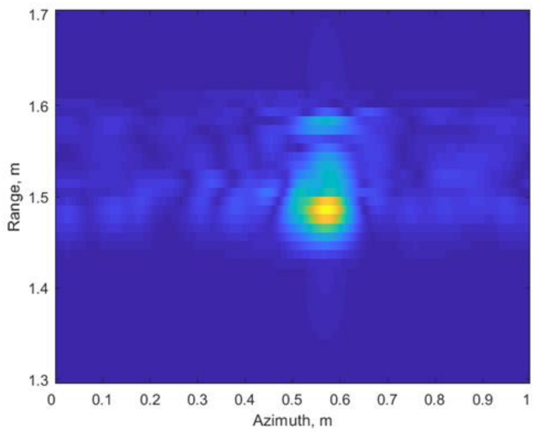


Fig. 14. Image reproduced by Blackman window.

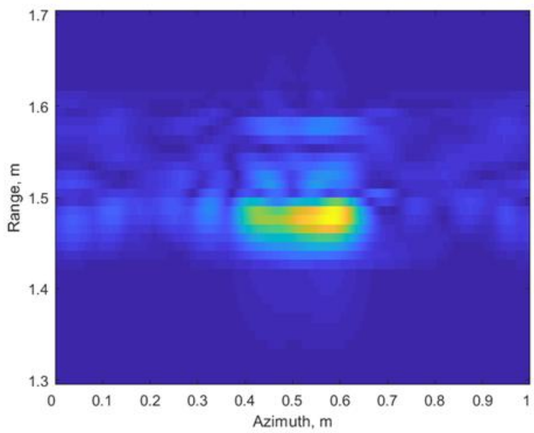


Fig. 15. Image reproduced by Kaiser window ($-\beta = 2.5$)

IV. CONCLUSION

In this study, we used UWB radar to see through a box with basic SAR Range Doppler Algorithm. In addition, the normal smooth window functions are applied to the time domain signal processing to achieve better results in object detection and interference and background noise rejection.

As the obtained results, the Kaiser window gave the best result compared to Rectangle, Hamming, Hanning and Blackman windows in image resolution. In the future, in order to improve the resolution of image for smaller object and see through wall application, we will apply Compressive Sensing method and optimization algorithm with smoothing window to achieve greater accuracy. With the ability in short range communication, we will study to apply UWB radar in defect detection of structure for non-destructive health examination test.

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