Modern Radar Topology for Bio-medical Applications

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Abstract Radar was associated with military industries in earlier centuries. This day's several industries, like automobile, mining, medical, etc., are also using radars. It is becoming very popular for contact less bio-medical investigation on human body, because of its less microwave energy radiation over short distance. Continuous monitoring of cardio respiratory activity, breast tumor diagnostics, imaging of blood circulation are few immerging areas of research in bio-medical applications. Continuous wave, frequency modulated, ultra-wideband, these are few popular radars which researcher start implementing in bio-medical application. Now recent radar topologies, mainly advance antenna technologies, like MIMO, array and Phased MIMO radar are also becoming very popular in medical applications because of effective performance ability in low signal-to-noise ratio environment. On the other hand, advance computational techniques like soft computing is also becoming part of the modern radar which can improve noise performance Doppler tolerance in bio-medical application.

Keywords RADAR · MIMO · Array · Phased MIMO · Soft computing · AI

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1 Introduction

The idea of remotely monitoring human body functions was generated in nineteenth century [1, 2]. In twenty-first century, radars are penetrated into civilized society from war field. In several ways, radars are helping society in regular activity. Bio-medical is one of the areas in which radar researcher puts a significant effort to make a difference. Non-contact continuous less harmful human body monitoring the idea of nineteenth century now became a key target using radar imaging. In a short distance scenario, a radar signal illuminating a human body for imaging is a very low-power microwave signal and less harmful than a X-ray imaging, but at the same time a very challenging job also. Continuous heartbeat monitoring, breast tumor and other tumor diagnostics, imaging of blood circulation are few challenging areas for active researchers. Low-intensity bio-medical signal detection and processing using modern radar are the main area of work. Initially, researchers start working with popular radars like CW [3], FMCW [4], UWB [5], Doppler [6], etc. In case of heartbeat monitoring or pulse rate monitoring, Doppler processing is one of the common practices. The main objective of the work is divided into three parts: (1) clear target identification: In an active zone, several living and non-living targets are present, so it is essential. (2) Mutual interference rejection: It is very important in case of adjacent subject elimination and(3) Vital signs or symptoms identification with minimal noise and less errors. But always these objectives become challenging due to low SNR bio-medicals signals. So, researcher starts thinking about multi-antenna techniques which can improve low noise signal detection and also thinking about soft computing toll which can efficiently process bio-medical radar data to provide error less monitoring of physiological functions. Multi-antenna techniques are already well established for low SNR signal in communication, even in radar also. The same multi-antenna radar can be very useful for bio-medical radar also. From here, use of MIMO, array and phased MIMO radar are in research for bio-medical applications. This radar uses multiple number of antennas in the transmitter and receiver side. The number of antenna elements creates simultaneous transmission and reception paths to improve the SNR and robustness of the signal [7]. The challenges under this part, to reduce the numbers of antenna in MIMO array configuration [8], reduce the interferences between collocated transmit received antenna elements [9] and calculations of coupling behaviors which effects on array performance [10]. By overcoming these challenges, modern radars are capable to handle with bio-medical signals like heartbeat. Heartbeat and respiration, both information can be trace from chest displacement which is a non-contact measurement. Heartbeat variation is ranged between 0.2 and 0.5 mm [11], but respiration displacement is higher than heartbeat; now, to filter out this type of different signal, radar system needs strong computational tools in which soft computing is helping a lot now a days. Soft computing tools like neuron network can help to classify bio-medical radar signals in a very efficient way.

2 Bio-medical Applications

2.1 Pathological Applications

In every medical emergency, doctors mostly depend on pathological test, which need body contact activity with patient, time consuming and expensive. Microwave imaging is getting popular for last few years for pathological applications. This type of pathological test is done with the help of radar by illuminating human body using closely spaced antennas and acquisition of the signal echo. Wisconsin-Madison University, Bristol University and Calgary University developed the best cancer detection system following confocal microwave imaging (CMI) technique. Similar pathological test is done on human bladder, hemorrhagic stroke in the head [12] and various others.

2.2 Remote Monitoring on Health Condition

Remote monitoring of health condition known as vital sign monitoring is basically contactless and continuous monitoring of our body parameters like heartbeat, breath and respiration activity. Not only that, bio-medical radar also experimented to measure blood vessel movements and to sense speech. This information is generally extracted by processing the radar echo in time domain. This continuous monitoring is very much effective to prevent infant death syndrome (SIDS) or sleep apnea; even this can be used in automobile industry which can monitor and alert drowsy driver to avoid critical situations.

3 Radar Topologies of Different Times for Bio-medical Uses

3.1 Continuous Wave Radar

Continuous wave frequency modulated (FMCW) radar is one of the popular radars under this category in which S_x is considered as radio frequency wave which is transmitted over space and the reflected signal from object is denote by $S_{r.}$

$$S_x = \pi r^2 \cos \emptyset(t), \quad \text{where } \emptyset(t) = 2\pi \int_0^t F(t')\mathrm{d}t' \tag{1}$$

$S_r(t)$ is the received signal by radar which consist of:

$$s_r(t) = \sum_m c_m \cos \emptyset(t - \tau_m) \quad (2)$$

Here, c_m reflects strength independent to each target and τ signal transmission from the radar toward the target and back. In a micro-power, FM radar is designed and developed to measure human heart rate and monitor respiration. Respiratory and cardiac rates are measured using radar as well as using conventional method. Multiple objects are tested from a single measurement under same research article using FM radar. A good range resolution capability is noted in this experiment.

3.2 Doppler Radar

Doppler radar is a type of continuous wave radar; it uses the Doppler effect signal for motion detection. Doppler radar can extract distance and phase information which helps to measure the vital signs of human body. Researchers are targeted to solve several problem areas listed below using Doppler radar: (1) clear target identification; (2) elimination of mutual interference, especially in the case of two adjacent subjects within range resolution limit; and (3) vital sign retrieval with minimal ambient noise. Doppler radar generally follows a three-step process in medical signal analysis. In the first step, the data acquisition takes place using radar hardware for which the human object needs to place very nearby to the transmitting antenna. Next, feature extraction takes place in which signal parameters are analyzed using different algorithms. Frequency estimation is generally done by MUSIC algorithm, and FFT algorithm is generally used for phase history profiling. These signal information are required in range integration for vital signs extraction. Respiration and heart rate retrieval can be done using auto-regressive (AR) method, which comes under the final step.

Commonly, the chest displacement due to respiration and heartbeat variation is ranged between 4 to 12 mm and 0.2 to 0.5 mm consequently. On the other hand, variation of respiration rate in rest position is between 0.1 and 0.3 Hz, while the interval of heartbeat rate varies between 1 and 3 Hz. Therefore, the signal contains both respiration and heartbeat where the respiration displacement is large than heart-beat because of that a filtering technique is needed to filter noise and unwanted signal from raw detected signal.

3.3 UWB Radar

An extremely short pulse is the key to generate an extremely high bandwidth. The radar system is categorized in terms of functional bandwidth (B_F) as given below:

Narrowband (NB) if $0 \le B_F \le 0.01$.

Wideband (WB) if $0.01 \leq B_F \leq 0.25$.
Ultra-wideband (UWB) if $0.25 \leq B_F \leq 2.00$.

The UWB radar is developed using strobed sampling method for detection of heart rate through wall. A human object is placed opposite side of a clay brick wall, and the reflected pulses from the object return into the received antennas through the wall. Now, the radar receiver will receive two types of signal due to two different types of reflection object. The signal reflected back from the wall can be treated as stationary signal which has a time variant characteristic, and the part of the transmitted signal reflected back from human object can be treated as nonstationary signal in which phase variation will occur due to human heartbeat and respiration.

These radars are exposed to a human body for perimeter monitoring; here health hazard issue taken under consideration, this happen due to microwave radiation towards human body, by the radar. In [13], safety aspect of people is taken under consideration for UWB radar. In this article, the compliance of electromagnetic fields radiated by a UWB radar as per International Commission on Non-Ionizing Radiation Protection (ICNIRP) is evaluated. UWB radar SAR limit averaged over whole body (SAR_{WB}), SAR as averaged over 10 g in the head and trunk (SAR_{10g}) and in the limbs (SAR_{10gL}) are reported under these article. The radiation limit of UWB radar used for medical signal processing and perimeter monitoring of human body between 3.1 and 10.6 GHz shall not exceed the EIRP value of −41.3 dBm,

3.4 *Modern Radar in Critical Medical Applications*

Modern radars are enabled with multiple antennas and more advanced signal processing. This type of radar is used for two-dimensional or three-dimensional imaging of the human body which can be used for medical diagnosis. Mainly, two types of microwave imaging techniques are used in breast cancer detection; first is tomography and another confocal imaging. A complete electrical profile of breast is attempted to map in tomography imaging which needs an antenna array to receive a passive electromagnetic field of the body [14]. In the confocal imaging, location of the significant scatters is mapped, which also explore the antenna array.

The multi-antenna system will increase the cost, size and complexity. So our aim is to design an array system with a minimum number of elements. The number of the antenna element can be determined by sidelobe level (ISL) idea, which can be calculated from Eq. 1:

$$\mathrm{ISL} = -20\ \log_{10} N_E \tag{3}$$

where minimum number of element is represented by N_E.

Transmit and received antenna number can be derived from Eq. 4:

$$N_E = N_{Tx} \cdot N_{Rx} \tag{4}$$

N_{Tx} is the number of transmit antenna element, and N_{Rx} is number of received antenna element.

The total number of antenna in antenna array is:

$$N = N_{Tx} + N_{Rx} \tag{5}$$

Here, the main challenge comes to choose the number of antenna elements and to deal with coupling between them to construct the antenna array. Phased array creates a problem due to network feeding loss, and also, there is some problem of far field as the object is closely placed to the antenna in medical diagnosis. Near field-focused antennas are in research for a long time for this type of application. Array configurations of NF-focused microstrip antenna are very useful to concentrate the signal power in a specific small geographical area using the beam forming method. This can heat a convicted tissue without affecting the adjacent one by concentrating the microwave energy into a specific spot, here are the advantages of modern technologies in radar.

3.5 Intelligent Radar

The strong computation techniques are used to process complex data matrix, received from multiple antenna in modern radars. Another complex computation is used these days to introduce intelligence in radar system. The modern radars are becoming intelligent day by day in which artificial intelligence (AI), deep learning and machine learning are becoming important parts of the system. In two ways, intelligence can be incorporate in radars, (i) by improving the pulse compression technique, which is unique target detection ability, used in most of the radar system, (ii) by reducing the repetitive task and increasing the diagnostic precision in medical radar.

In article [15], the improvement in pulse compression technique using artificial neural network (ANN) is shown. Adaptive filter algorithms are very useful to find optimum matched filter coefficients for pulse compression technique. This can be efficiently designed using multi-layer perceptron networks with adequate weight and bias parameters under ANN. Back-propagation algorithm (BPA) is used to implement multi-layer perceptron networks. It is an intelligent pulsed compression process which can be used for intelligent radar which researchers are targeting near future. How ANN can improve the performance and how to optimize the filter coefficient that is analyzed using convergence rate analysis. This is done by varying neurons and hidden layers and by applying different adaptive filter. Noise performance and Doppler tolerance test is also done to determine the performance enhancement (Fig. 1).

AI or ML algorithms can analyze a pattern similarly to the way a doctor analyze it; this is another vital area in which intelligence is contributing a lot. In article, convolutional neural network (CNN) is discussed which can help for radiology. Convolutional neural network (CNN) is the widely used deep neural network in the

Number of neurons in the HIDDEN LAYER	SNR = 1 dB	SNR = 5 dB	SNR = 10 dB	SNR = 15 dB	SNR = 20 dB	SNR = 25 dB
1	0.2697	13.965	37.8197	41.6916	43.2368	43.5327
3	1.1668	19.8091	37.8114	40.8114	42.1449	42.8214
5	4.1712	20.1232	38.7173	41.4815	42.6685	43.2707
7	2.041	21.6259	39.8674	42.653	43.7414	44.2466
9	5.3084	27.8965	41.0523	44.582	45.9905	46.7106
11	3.5948	14.7718	32.9811	44.0575	46.1658	46.4402
13	9.0224	21.303	37.0488	43.7983	46.2642	46.7362
15	3.7224	15.8543	35.0372	44.1597	46.3064	46.5465
17	3.8924	16.8811	37.886	44.3849	45.8557	46.1104
19	5.6383	20.9294	36.2993	43.0907	45.8804	47.3765
20	4.0719	16.1363	33.6252	43.4301	46.2728	46.8659

Fig. 1 Signal-to-sidelobe ratio (SSR) improvement for pulse compression technique using MLP

area of image classification, object detection, text recognition, action recognition and many more CNN was initially inspired by visual cortex of animals, For large volume images like RGB images, ANNs lead to an explosion in the number of weights which requires more memory and computation data. This problem can be solved using CNNs by using the sparse connections and parameter sharing. Like ANNs, CNNs also have neurons, weights and objective. The major properties of CNNs are the presence of sparse connection between the layers and the weights which are shared between output neurons in hidden layer (Fig. 2).

Convolution is basic component of CNN which performs feature extraction; it is basically combination of nonlinear and linear operation. The input is an image that will hold pixel values. It has three dimensions such as width, height and depth (RGB

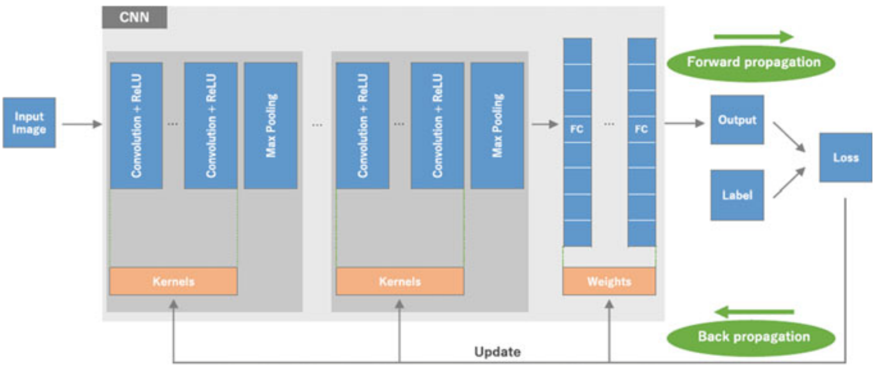

Fig. 2 Overview of a convolution neural network (CNN) architecture and the training process

channels); example is [50 × 50 × 3] [16]. The convolutional layer will compute the output of neurons that are connected to local regions in the input. The layer's parameters are composed of a set of learnable filters (or kernels), which convolved across the width and height of the input volume extending through its depth, computing the dot product between the entries of the input and the filter. This produces a two-dimensional activation map of that filter, and as a result, the network learns filters that trigger when it detects some particular type of feature at some spatial position in the input. The function called rectified linear unit (ReLU) layer will perform elementwise activation function. ReLU is defined in (6),

$$(x) = \max(0, x) \tag{6}$$

This function is zero for negative values and grows linearly for positive values. This will not affect the volume size. The pooling layer outputs the maximum activation in a region. This down samples the spatial dimensions such as width and height. The output layer is the fully connected layer which is similar to the final layer of the neural network. This layer used commonly used softmax activation to output probability distributions over the number of output classes. Few popular CNN architecture is available in the market; those are LeNet, AlexNet, VggNet, GoogleNet, ResNet. These can be very much helpful in medical imaging.

4 Conclusion

Like every sector, radar industry is also needed to be intelligent, in which the use of AI-ML is incensing day by day. In this article, the authors try to find out the angles in which intelligence can be incorporated in radar. Basically, two directions are highlighted in this paper in which the work is going on. In one way, radar baseband is becoming more adaptive by using adaptive filters, and also, ANN techniques are used for improving pulse compression technique which is the heart of the modern radar. This type of works are increasing the detectibly and decreasing the chance of false alarm rate. Few works are discussed in this direction, which helps us to find a new area in radar domain. In other direction, CNN technique is discussed for improving the radiometric imaging and can be very helpful in medical radar. In this part, AI will help a lot to reduce the repetitive work, and using a huge number of training databases, a preface radio diagnosis is possible in medical field. Basically, this article discusses about the AI techniques, namely ANN and CNN, that can be very useful, especially for medical radar, which will help us a lot for heart rate monitoring, breast cancer detection and many more.

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