CHAPTER 6

Conclusions and Future Scope

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6.1 Conclusions

The objective of research work embodied in the present thesis was 'Signature Detection of the Indoor Objects using Microwave Imaging and Ranging Systems,' that is essential to monitor any unusual activities at any public access site like hospitals, schools, etc. Further, it facilitates to rescue operations in case of any disaster. The motivation for this signature detection study was to provide simpler, flexible, and highly efficient detection methods of human beings under rest as well as movement conditions.

In the rest condition, the location of any subject of interest is essential information for security and rescue reasons inside an observation area. Microwave-based solutions are already available in the literature for the indoor location finding but proposing a cost-effective, flexible, and non-bulky system is still a challenge. This thesis presents a review on target localization that has been widely accepted and applied by various researchers and practitioners for the indoor environment. However, the used systems involve extensive data collection, complex information fusion mechanisms, and demands receivers with high sensitivity. This thesis proposes an improved target localization system comprising two antennas with very high location estimation accuracy using the algorithm based on the common region of sensing of the two antennas available in the observation region. In addition to that, the literature survey on human target detection using its vital sign characteristic frequencies in free space conditions has been carried out in the thesis. However, practical military or disaster rescue conditions demand human detection through the wall (hurdle). The detection task becomes quite challenging due to a high amount of clutter offered by the wall that hides the subject's associated reflections. The thesis proposes a novel method to enhance the relative information of the subject associated information with respect to the wall, facilitating the detection of the vital sign characteristics for human presence.

Furthermore, in human movement conditions, the thesis covers the exhaustive review on micro-Doppler (m-D) based activity classification. Most of the methods covered the classification of human activity associated micro-Doppler information based on time-frequency features or their variants, which demands the user's ability to analyze the m-D spectrogram or its portion. The other concern is to define complex processing for feature selection. The thesis presents a texture analysis based method for feature extraction, which reduces user intervention or the complication of time-frequency domain feature definition procedure. The method yields a very great improvement in final classification results and produces the validation accuracy up to 96.7% for multiclass activity classification problems. Most of the literature based on m-D analysis assumes that only a single target class is present at the time of observation in the radar channel. However, at any practical site, there is a huge chance of the presence of other moving targets along with the desired target in the radar observation channel. We propose a deep neural network (DNN) inspired time-frequency based masking approach for the desired target response separation for a practical activity monitoring system.

A two-antenna based target localization system working on the principle of stepped frequency continuous wave (SFCW) radar was synthesized with the help of a vector network analyzer (VNA) anywhere inside a rectangular region is discussed in *Chapter 2*. Within the common region of sensing (CROS) of the two antennas of the designed systems, the sub-regions were identified, which governs the target position estimation after range measurement. The object location was determined in a simple

Cartesian coordinate defined concerning the system's two antennas. The two-fold capability of the proposed algorithm was assured by performing the two types of experiments. The first experiment covers the free space localization capability, where the target was placed at the entire area of the room's available space at 35 different locations. For this case, the estimated coordinates obtained the maximum deviation from the actual position was 8.03 cm for a cylindrical target of 30 cm radius. On the contrary, in the second type of experiment, the system was tested for through the wall localization capability. The same cylindrical target was placed at eight different positions, while the localization system was placed behind a plywood wall of thickness 1.1 cm 2.2 cm. The maximum error corresponding to both wall thickness was 4.79 cm and 7.18 cm, respectively. The maximum error obtained in all the experiments lies within less than the target radius and falls under true detection, and system performance was obtained 100% true estimate. The proposed system's target localization accuracy was obtained very high in all the available space of the rectangular observation region for free space as well as through the wall conditions.

In *Chapter 3,* the remote detection of the human presence behind a wall by exploiting its physiological characteristic like heartbeats has been explored. An SFCW radar system operating in the C-band frequency range (covering 4-6 GHz frequency span) by incorporating vector network analyzer (VNA) and the antenna was used in the experiment. To perform the coherent operation of VNA for multiple sweeps, the interfacing has been done using MATLAB Instrument Control Toolbox and programmed to capture 400 consecutive sweeps with 201 frequency steps. In the radar return, to suppress the strong wall reflection and enhance the associated human signals, a singular value decomposition (SVD) based clutter-reduction approach was applied on the multiple sweeps stacked data translated in the spatial domain. The moving target indicator (MTI) filtering was applied in each range been of the stacked spatial data to clean out the static clutter present and sustain the moving target responses. The application of SVD based clutter-reduction improves the target signal to wall clutter ratio from 35% to 489%; thereby. Thus, making it possible for life feature detectable by MTI for through the wall detection. The test subject's detected heart beating rate was obtained 1.42 Hz at a distance of 2.85 m from the bi-static radar unit. It was observed that the proposed processing method is able to detect the presence of human heart rate characteristics frequency in radar downrange direction for a through the wall sensing scenario; hence can be used for military and disaster rescue purposes practically. However, the detected target location is at a higher distance compared to the actual location, which needs to be adjusted.

The classification of human movements, useful for site security monitoring applications, was generated using RF micro-Doppler signatures and described in *Chapter 4* of this thesis. These human activities include the occurring of activities arising in any living area in daily life like (i) walking with pushing some large object (chair), (ii) walking, (iii) walking with holding some small object by both hands, (iv) swinging single hand (v) swinging both hands. For distinction of these activities, spatial features extraction based classification method was used to facilitate the least human intervention and interpretation of micro-Doppler spectrograms corresponding to each activity. The different human movements' activities were generated by different volunteers and captured by the synthesized coherent system in the laboratory, operating typically at 6.5 GHz continuous wave (CW) frequency. The high sampling rate (1 kHz) time-domain data was captured corresponding to each experiment during data set creation. To obtain the time varying micro-Doppler information present in the time series data, spectrogram generation was achieved using sliding time window Fourier transform. The spatial features were defined for the spectrogram images using statistical analysis of image time-frequency cell intensities. The features and their combination were utilized for training and predicting using one versus rest support vector machine (SVM) classifier. The classifier's training phase includes 80% of the total collected data, while the remaining 20% of the data were used for validation. It was observed that the classification accuracy of each individual feature was different when they were used separately to train the SVM. By increasing the use of training features from one to five, it was found that classification accuracy gradually improved over previous results. On the application of five features, the classifier's accuracy during the validation phase was 96.7%, while during testing, it was observed greater than 93.33%. The proposed technique was also compared with those available methods reported in the earlier literature and found superior in terms of validation and prediction accuracy for multiclass classification having the least processing complexity. The high accuracy of the proposed algorithm for multiclass classification problem shows that it can be implemented as a generalized tool.

Chapter 5 deals with the necessity of m-D signature recognition and differentiation occurred at any security observation sites to distinguish any unusual activity. It is not necessary that always a single moving target is present in the observation of single-channel radar, and due to that, the analysis may suffer in the distinction of the actual target of interest. In this chapter, the data corresponding to the individual classes are captured and reported in the literature by a developed single-channel CW radar was used as a clean condition data, and consequently, the mixed Doppler responses were also generated by using the superposition principle. The mask corresponding to the combination of mixed m-D response and clean condition response was created using soft masking methods in the time-frequency domain. A regression deep neural network (DNN) with one input, one output, and two hidden layers have been designed to address this single-channel source separation problem. The designed mask corresponding to the activity class and mixed m-

D signature was used for the training purpose in the network's training phase. When the mixed signature is provided in the prediction phase, the trained network predicts the mask corresponding to the desired activity. The signature of three separate classes of movants forward walking human (FH), backward walking human (BH), and a rotating table fan (TF) in front of a CW radar have been utilized in this study to solve the separation of response problem in the study. The proposed method was tested for the separation of the desired signal from the mixture of two and three moving target classes. Through qualitative analysis and visual inspection, it was observed that the desired target's generated spectrogram appears quite similar to clean condition spectrograms and easily can be identified. A correlation of separated desired m-D with the original (clean condition) m-D response of the desired target was 98.07% and 96.33% for the simultaneous presence of two targets and three target cases in the channel, respectively. The higher amount of correlation of the separated signal with the original signal before mixing (clean condition response) indicates the proposed method's potential utilization for site security monitoring and surveillance purposes.

6.2 Limitations of the Study

Since all the experiments used in this thesis are done using network analyzers. The precautions mentioned in user manuals and data sheets of VNAs have been strictly taken care of to conduct the experiments to minimize the error. Each time, before starting any experimental session as per the study requirement, calibrations have been done to fix the instrument parameters unchanged throughout the experiment. The operational specification prescribed by network analyzer manufacturer have their own inbuilt errors on temperature sensitivity has been overlooked during the experiments. Following bulleted information highlight the limitations arise during present work:

- For through the wall system studies, the experiments were limited to a plywood wall of small thickness. In real-time scenarios, the wall thickness and material dielectric constant can vary, thus resulting varying loss in the received signal strength. Due to this, there shall be low SCNR that forces detection challenges and delay in target range estimate.
- For the purpose of accomplishing the study objectives, the performed experiments were limited (a) inside an anechoic chamber for target localization and human heartbeat detection; (b) by employing microwave absorber sheets to collect micro-Doppler classification data to avoid the influence of unwanted targets of surroundings.
- For the target localization system study, the antenna beamwidth need to be sufficiently high in order to the successful implementation of the CROS algorithm. Due to the non-availability of the wide beamwidth antennas, the experimental setup was designed with rotation provision on each available X-band antenna. This limitation of experimental arrangements restricted us in real-time based continuous data, hence restricted to develop a tracking system.
- The study of human heartbeat detection was limited to the assumption that the test subject 'torso' lies inside the radar field of view such that the small movements at the torso surface can be sensed. Thus, the experimental design was limited to adjust the antenna manually at a certain height from the floor to project the RF radiation on the test subject's chest area.
- For deployment of activity classifiers at any application site, the training data set size should large (around 500 sets), and the number of volunteers should be more of a different physical appearance and build to get better algorithmic accuracy. In

our case, we have taken only 150 sets of data and performed experiments with three volunteers due to time and resource constraints and limitations.

6.3 Future Scope

Since the works conducted in the thesis require the assembling and recodification of experimental arrangement and surroundings, apart from that, the covered works also demand volunteering of other human resources. Due to the limited resources and time, some of the activities in this thesis could not be addressed and suggested as future scope. In this thesis, the works have been carried out to detect living human beings' signature for two broader categories. Where the first category deals with a ‘state of rest,' while the second includes the human's movements during some activities being performed by the human subject.

For ‘rest scenario’ measurement, ultra wide-band (UWB) systems have been used for the position and life characteristics detection. For such scenarios, the following may be the more prospective and future agenda of research:

(i) The two antennae based proposed localization system has been tested for the distributed locations of the target in a single 2-D plane; however further study can be explored for dynamic tracking (varying time followed by varying coordinates) of a lively moving target in a 2-D plane within the common region of sensing (CROS).

(ii) By following the para (i) suggestion, the work can be further extended for a three-dimensional space for target localization with a dynamic tracking facility.

(iii) The research work presented in chapter 3 dealt with detecting life sign characteristics in the one-dimensional downrange direction. However, by incorporating two antennae-based systems and a proper information fusion technique, a live human being can be located in a two-dimensional plane with its *x*-*y* coordinate values.

For the second case, i.e., human subject in moving condition, the thesis has addressed moving targets' classification on behalf of micro-Doppler's spatial features and separates out the human signature from the mixed micro-Doppler of multiple movers for further analysis. Apart from these studies, the following future extended research may be carried out for human detection in moving conditions:

(iv) The potential of spatial features to classify the human activity is very high (above than 96 %) for five human activity classes; however, the study covered is done on a small data set of 150 experiments. There is a further scope in chapter 3 to apply the proposed method on relatively large data size to test the proposed method's actual classification efficiency.

(v) The classification method was applied to five classes of movement, which is a significantly less span to cover all possibilities occurring in a surveillance region. To make a practical activity recognition and classification system, there is a need to test the proposed method on a wider variety of movement classes.

(vi) This can be further extended to solve the classification problem of more number of human activity classes and create a database of m-D activities. The study based upon masking and the deep neural network has separated the desired target micro-Doppler response from multiple movers' mixed information in a single radar channel. This concept can be further applied to decompose the human limbs' signature on the experimentally collected data.