7.4.1 Pre-processing

The main purpose of this stage is to clean and prepare the collected data for classification. The steps of the pre-processing stage are:

7.4.1.1 Data collection

For HAC using UWB radar, the backscattered signals at different time of arrivals, i.e., different ranges from the radar, can be successively gathered. Then, the reflected echoes $r(t, T)$ are sampled and recorded in a 2-D data matrix $R \in r(mt_i, nT_0)$ as follows:

$$R = \{R^{(m)}[n]: m = 1,.., M; n = 1, ..., N\}, \quad (7.15)$$

where m and n represent the propagation and the observation time index, respectively.

The output of the sensor system is a data matrix R (radargram). The range-profiles are stored in M range-bins which is the number of the columns of the matrix R. Each scan, representing the reflected signal, has a data vector of length M. The radar scans are stored in N scans every 0.0025 seconds (400 scans per second), which represents the rows of the matrix R.

7.4.1.2. DC removal and stationary clutter suppression

The main purpose of this section is to remove noise, DC, and stationary clutter. This is done by subtracting the mean of the collected data matrix in slow time. After that, the background subtraction method is used to remove the stationary clutter from the backscattered signal R. This method is applied by subtracting the estimated background of each range bin over the observation time i.e. $z(m) = R(:, m)$ from the measured signal as shown:

$$x(m) = z(m) - p(m - 1), \quad (7.16)$$

The estimated background *p(m-1)* is calculated using the moving average method; the estimation technique uses the average of previous L samples to estimate the background of the reflected signal:

$$p(m - 1) = \frac{1}{L}\sum_{j=m-L}^{m-1} r(j), \quad (7.17)$$

The simplest case is moving target indicator (MTI) that considers L = 1, where simply the background is assumed to be equal to the previous sample. In this paper L=30.

7.4.1.3. Non-stationary clutter suppression

In addition, the non-stationary clutter should be suppressed. For this purpose, the resulting output of stationary clutter reduction is a matrix$X$, where $X \in^{N\times M}$. SVD calculates the lag-covariance matrix $C = XX^T$and its singular decomposition. If N ≥ M, then the SVD of X can be written as (7.18):

$$X = U\Sigma V^T, \tag{18}$$

where, $\Sigma = \binom{\Lambda}{0}, \Sigma \in^{N\times M}$. Notice that for $N \leq M,\ \Sigma = [\Lambda \quad 0]$ is the diagonal matrix of eigenvalues, with $\Sigma = diag\ (\sigma_i, \cdots, \sigma_R)$; σ_i is the singular values sorted in the descending order; $U \in^{N\times M},\ U = (u_1, u_2, \cdots, u_N)$ and $V \in^{N\times M}, V = (v_1, v_2, \cdots, v_N)$ are the matrix of empirical orthogonal functions and the matrix of principal components, respectively, where $U^T U = I, V^T V = I$.

The data matrix may be thought of as the summation of M individual singular-value matrices, each given by (19)

$$D_j = U\Sigma_j V^T, \tag{19}$$

$D \in^{N\times M}$, $j \in \{\, 1, \cdots, M\}$, Σ_i is a matrix of the same size as Σ in which all elements are zero except $\Sigma(j,j)$.

The data matrix X can be rewritten as (20):

$$\begin{aligned} X &= X_{cutter} + X_{target} + X_{noise} \\ &= \sum_{a=1}^{A} U\Sigma_a V^T + \sum_{b=1}^{B} U\Sigma_b V^T + \sum_{c=1}^{C} U\Sigma_c V^T \end{aligned} \tag{20}$$

clutter, target, and noise, are represented by the set of eigentriples A, B, and C, respectively. SVD is used to detect the target signals and remove the contribution of $X_{clutter}$ and X_{noise} i.e., clutter (stationary and non-stationary) and noise, respectively. Clutter mainly results from the environmental reflections occurring where the measurements are performed e.g., from walls, static objects, non-static objects, and furniture.

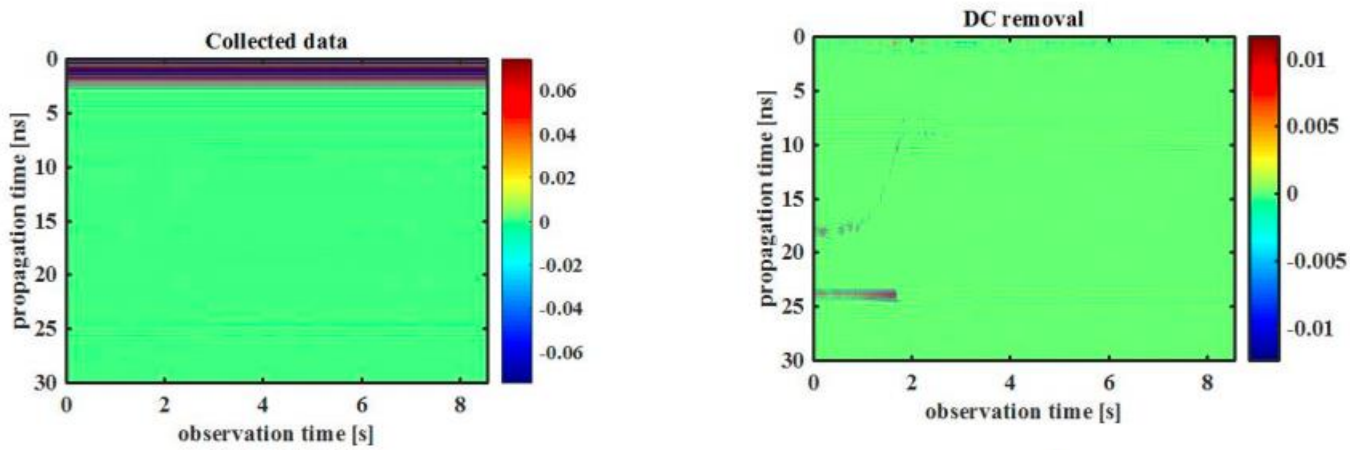
SVD operation is applied iteratively and the data matrix is reconstructed after removing the singular values that represent the clutter. The proposed method (based on the experimented data in chapter 4 and 5) shows that 2nd, 3rd, 4th, and 5th singular values

The proposed method (based on the experimented data in chapter 4 and 5) shows that 2nd, 3rd, 4th, and 5th singular values contain target information. When all other singular values are removed, the reconstructed data matrix is a matrix $Y = y_{i,j} \in^{N \times M}$.

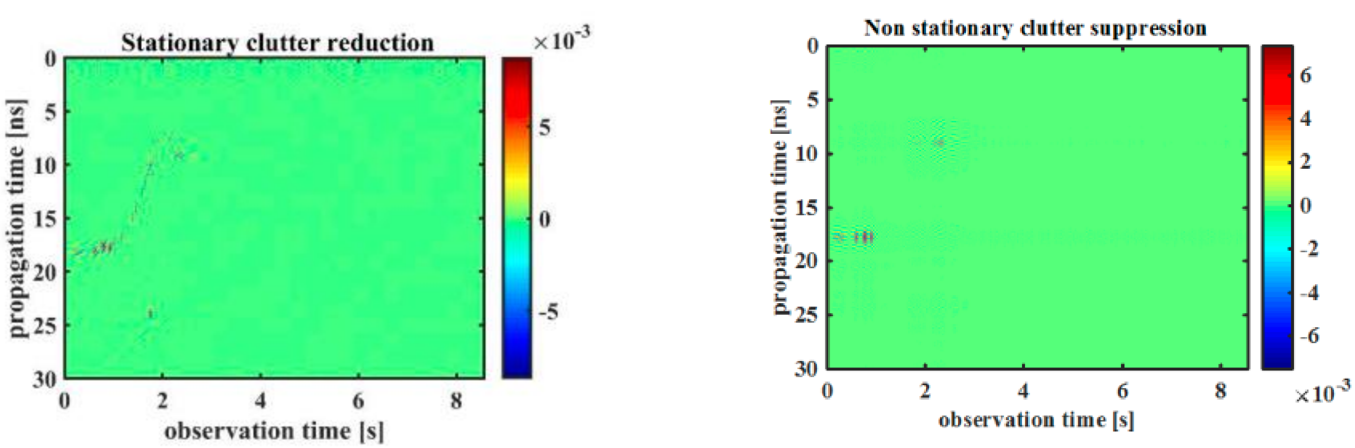
7.4.1.4. Summation and normalization

The resulted output matrix of non-stationary clutter suppression is a matrix $y_{i,j} \in^{N \times M}$, where N is the number of rows corresponding to observations recorded at different time intervals (slow-time, across scans), and M is the number of columns representing the spatial samples from different ranges (fast-time, only one scan). To prepare the input time series for the proposed HAC ML algorithms, and to calculate the spectrogram, the average of each impulse response (over the fast time) is calculated as follows:

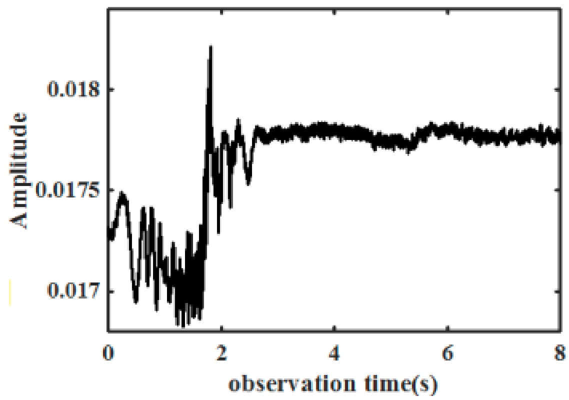
$$Y_i = \sum_{j=1}^{M} \frac{y_{i,j}}{\underbrace{\max(|y_{i,j}|)}_{j}} \tag{7.21}$$



(a) *(b)*



(c) *(d)*



(e)

Figure 7-5 radargram Collected radar data at different steps of pre-processing stage for fall forward human activity: (a) collected data, (b) after DC removal, (c) and (d) after stationary and non-stationary clutter suppression respectively (e) after averaging