Goal of the assignment

The goal of this assignment is to understand how UWB radar works, how to use the radar data collected from an array for localization and vital sign estimation.

Data Collection

Localization of walking in differnt patterns: We have collected data from a few participants where the participants followed different paths in the room. These paths include U-shaped path, L-shaped path, 4-shaped path etc.

Vital Sign monitoring in different postures: We have collected data where the participants lie down in bed in different resting positions and perform different activities. Below we can see a list of activities each participant has performed while wearing the Hexoskin T-shirt. The Hexoskin T-Shirt was used for ground truth data collection.

- Resting on the back (Soldier)
- Arm movement (Reading a book turning page/ Browsing mobile)
- Turn on to the left side and then right side
- Resting on the stomach (Freefall)
- Resting on Fetal position Right and then Left

You can download the data from the following link:
https://drive.google.com/drive/folders/1oOtnOtpwrlIjq6zgtCnr6Kj95XoOtdzd

Step-wise Localization

For the data collection we used three Ultra Wide Band (UWB) radar units called PulsON® 440 (P440) Monostatic Radar Module (MRM). Each sensor has an UWB transmitter and an UWB receiver. The transmitter and receiver operating band is generally, 3.1 to 4.8 GHz and the center frequency is 4.3 GHz. The three radars use sperate code channels to avoid interference among each other. UWB radar repetitively transmits short duration electromagnetic impulses having extremely low power and a very large bandwidth. These impulses incident upon both stationary and moving object and the reflected pulses travel back to the receiver of the UWB radar. The reflected pulses go through some signal processing steps in order to remove clutter (reflections from static objects such as furniture, walls etc.) and focus on the targets motion based on the round trip propagation delay of the pulses called time-of-flight (ToF). The targets range/distance can be easily calculated from the time of flight by multiplying it with the speed of Light (EM wave). The signal processing steps for clutter removal include band-pass filtering of the raw data and envelope detection of the motion filtered data.

(a)

(b)

Figure 1: The UWB radar units used for this data collection.

Thresholding:

After the envelope detection of the motion filtered signal one can observe the presence and movement of human body in the waterfall curve. By plotting a 3D plot of the envelope detected signal we can decide a threshold value for tracking the moving individual over time. This threshold can be different for different radars depending on farthest location of the subject from the radar location. A typical threshold value for the localisation dataset and room map is above $5 * 10^4$. In a given time instant, the range bins at which the signal strength is greater than the threshold determines the radial distance of the individual from the corresponding radar. UWB impulse radar (IR) can only provide range information based on time-of-flight (ToF) of the received pulses. That is why, localization in a 2D plane via UWB-IR requires more than one radar.

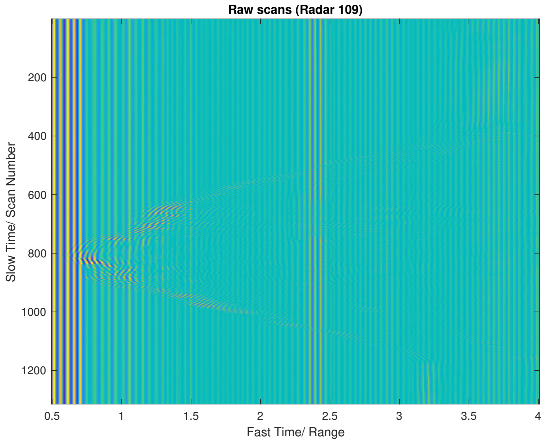
Time Synchronization:

In order to localize and track a moving person we need to synchronize consecutive observations of the target individual with its location. Therefore time synchronization of all three radar's observations is crucial. Using the provided Unix timestamps from each radar one can synchronize the envelope detected signals from all the three radars before applying any localization techniques. A time synchronized envelope detected plot is shown in Figure 3.

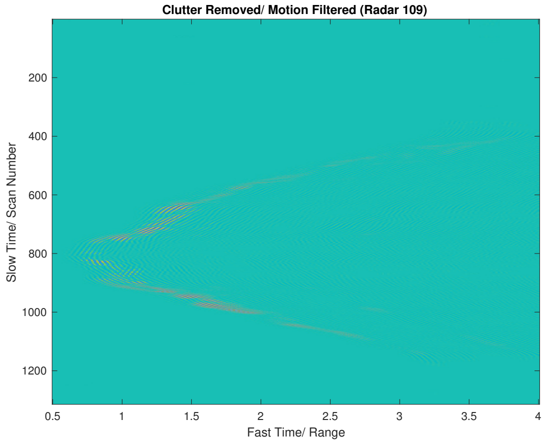
Trilateration:

Trilateration uses only the distance measurements to localize the target. After getting the synchronized consecutive observations of the three radars, the target range bins are obtained through thresholding. Now one can draw circles using this range as radius and the corresponding radar position as the center like shown in Figure 4.

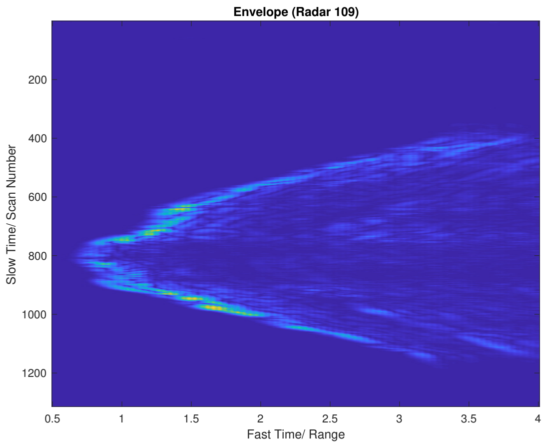
The intersection of these circles will provide the estimated location of the target in a 2D plane. However, it is expected to have multiple circles drawn for one radar for a particular time instant due



(a)



(b)



(c)

Figure 2: illustrates (a) the raw UWB radar data, (b) the clutter removed radar data and (c) the envelop of the clutter removed radar data in 3 different water fall plots. The range vs scan number plots are typically referred as water fall plots.

to multiple range bins (human target cannot be considered as a single point). It also depends on the Time_Window size and Time_Window_Shift size taken for analysis. More window results in more radar detections. Usually the Time_Window size is taken 0.25 seconds and Time_Window_Shift size is taken half of that. Therefore, there would be a bunch of intersection points for a single target. A geometric interpolation should be used to estimate target position using a properly created cluster of circle intersections. The gemetric centroid of the cluster is then the estimated location of the target individual.

After localization and tracking the 2D plane looks like the following figure which was obtained from walking in pattern "U".

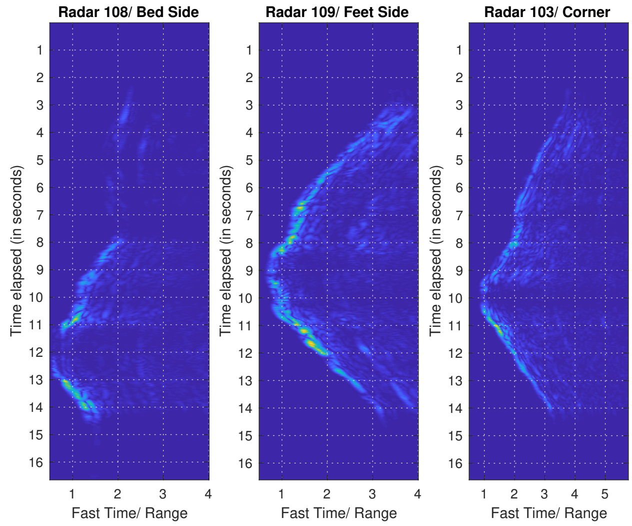


Figure 3: shows the waterfall plots of three time synchronized radar data.

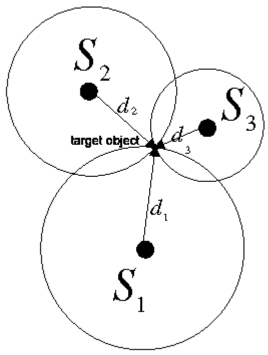


Figure 4: illustrates the trilateration process with the time synchronized radar data from 3 UWB radar units.

Shadow/ Mirror Location Fallacy:

In case of localization using only two radars in adjacent walls, shadow/mirror points might appear. This is due to the fact that two circle intersect twice in two different location. This mirror point does not appear in case of three radars. The mirror location can easily be avoided incorporating the room measurements (the intersection falling outside of the room dimension should be discarded). If two intersections is still available (which might occur in case of short radii) then the intersection closest to the previous observed location should be selected discarding the other one.

Vital Sign Estimation: In order to estimate the vital sign of the target individual we take advantage of his/her location information which in this data set is the bed location. Take the radar data which is closest to the bed location and focus on the range bins which cover the bed area. For example, if we take Radar 1, then we should focus on the range bins which correspond to the distance between 0.8128m and 1.8161m (The left edge of the bed is at 0.8128m and the width of the bed is 1.0033m, so the right edge of the bed is 0.8128+1.0033=1.8168m). Now for each scan you should take the maximum amplitude occurring at the focused range bins. These maximum values taken over all the scans will provide you the breathing signal in time domain. Make sure to perform mean subtraction

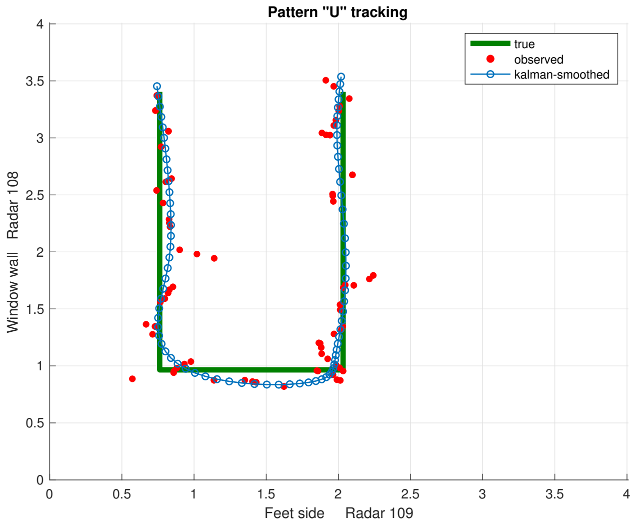


Figure 5: illustrates the localization and tracking on a 2D plane. Each red dot represent the geometric centroid of the clusters. The blue dotted line is estimated with the help of a kalman filter. For this assignment kalman filtering is not in scope for this assignment, so you will not have to worry about the smoothed blue lines.

for making the dc offset zero. Taking FFT of this mean subtracted time domain breathing signal will provide the breathing rate. The following figure shows the breathing signal and corresponding fourier transform after taking FFT for a breathing rate of 15 breaths per minute.

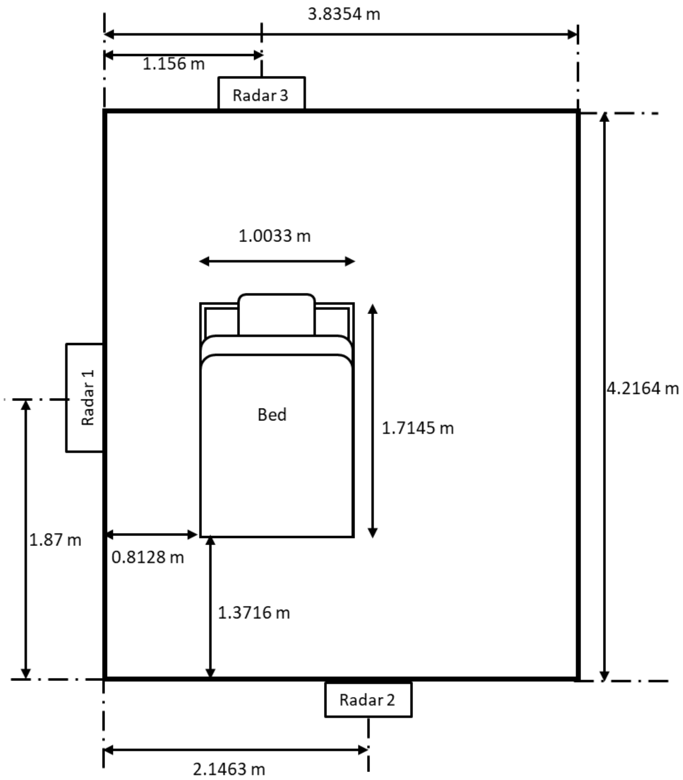


Figure 6: shows the map of the room that was used to collect the breathing data.

Data Organization

Vital Sign Data Set: The vital sign data can be found in the "Vital Sign" sub-folder inside the provided "DataSet" folder. There are two participant's breathing data in the two folders namely "BR_st1" and "BR_st2" inside the vital sign folder. Each of these folders has three radars folder namely 'Radar 1', 'Radar 2' and 'Radar 3' . Each radar has breathing activity in 7 different postures. Each posture has 3 **.mat** files namely 'rawscans.mat', 'range_bins.mat' and 't_stmp.mat' .

- The 'rawscans.mat' gives the raw radar scans which is a 2 dimensional matrix where the rows correspond to the 'Slow Time/Scan Number' and columns correspond to the 'Fast Time/Range' as seen in the figure (a). Therefore the value in i^{th} row and j^{th} column represents the magnitude of raw reflections the radar picked at j^{th} range bin from the radar in the i^{th} scan.
- The 'range_bins.mat' is an array containing the corresponding fast time or ranges in meters. For example, the first range bin is 0.5 meter, the second range bin is 0.509 meter and so on.
- The 't_stmp.mat' is an array containing the corresponding UNIX time stamps for each scan. You can convert UNIX time to real time using any available methods.

Localization Dataset: The localization data set can be found in the folder with the same name. It consists of two participants' walking data. Each participant has data from three radars namely '108', '109' and '103'. In each radar there are files for each walking pattern such as 'diag', 'U', 'gamma', 'L' and 'four'. Also there are three mat files provided in each walking pattern.

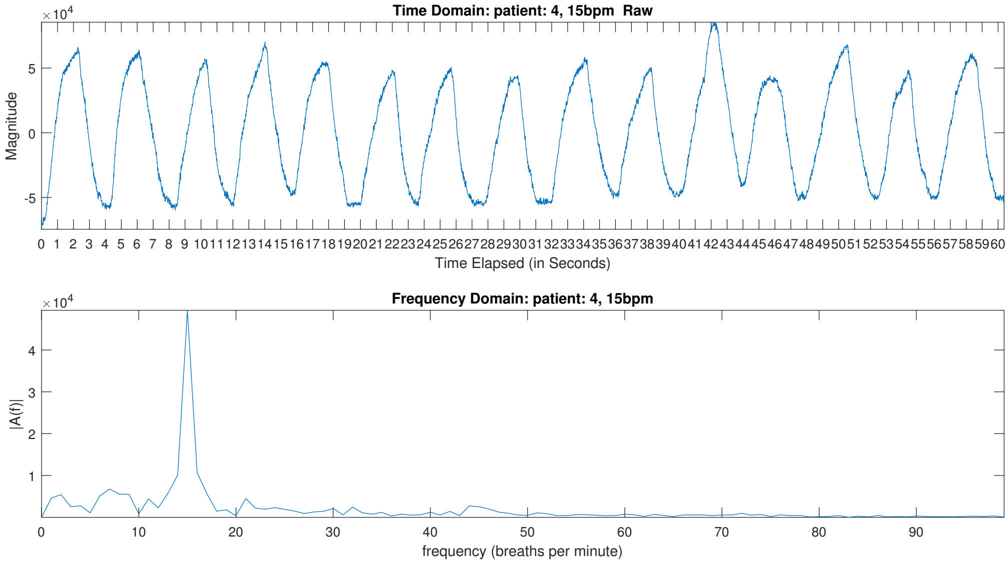


Figure 7: illustrates time domain breathing signal or waveform estimated from the radar data. On the bottom, we can also see the magnitude spectra of the signal (which can be obtained by passing the time-domain estimated breathing waveform through a Fast Fourier Transformation and by estimating the magnitude at different frequencies.)

- The 'envNoClutterscans.mat' gives the clutter removed envelope detected version of radar scans which is also 2 dimensional matrix like before, where the rows correspond to the 'Slow Time/Scan Number' and columns correspond to the 'Fast Time/Range' as seen in the figure (c). Therefore the value in i^{th} row and j^{th} column represents the magnitude of envelope detected scans at j^{th} range bin from the radar in the i^{th} scan.

- The 'range_bins.mat' and 'T_stmp.mat' are same as before.

The location of the radars and the walking patterns in room map are shown in Figure 8.

Data Analysis and Interpretation

- **Step 1 (10 Points):** Visualize the water fall plots of any one specific patterned walk activity for a single radar data. It should look like Figure 2c.

- **Step 2 (40 Points):** Perform localization in the localization data-set for both participants and all the patterns using trilateration method. Scatter plot the obtained location points in a 2D graph along with the ground truth patterns. It should look like Figure 5 except the kalman filtered part (Kalman filtering remains outside of the scope of our assignment).

  Hint: First try localizing with only two radars e.g. with R108 and R109 before fusing all three radars.

- **Step 3 (35 Points):** Using the Vital Sign dataset, draw the raw breathing wave forms for both participants and all different postures using the closest radar to the bed (i.e. Radar 1) and perform FFT on the breathing wave using the Vital Sign Estimation method described above. The output plots should look like Figure 7.

- **Step 4 (15 Points):** Now estimate breathing rates using the rest two radar's (Radar 2 and 3) data for both participants and all different postures and share the estimated breathing rates for all three radars in a tabular format. From your findings comment if there is any correlation between posture and choice of radar for breathing rate estimation. In other words, describe whether for a certain posture any particular radar works better than others and why?

Deliverables

- a report document, where you will put various plots and tables along with your interpretation of these results (in the plots and tables)
- all of your code. Please attach your full code. Please provide us with further information and documentation so that we can easily run your code. Try to comment your code for better readability.

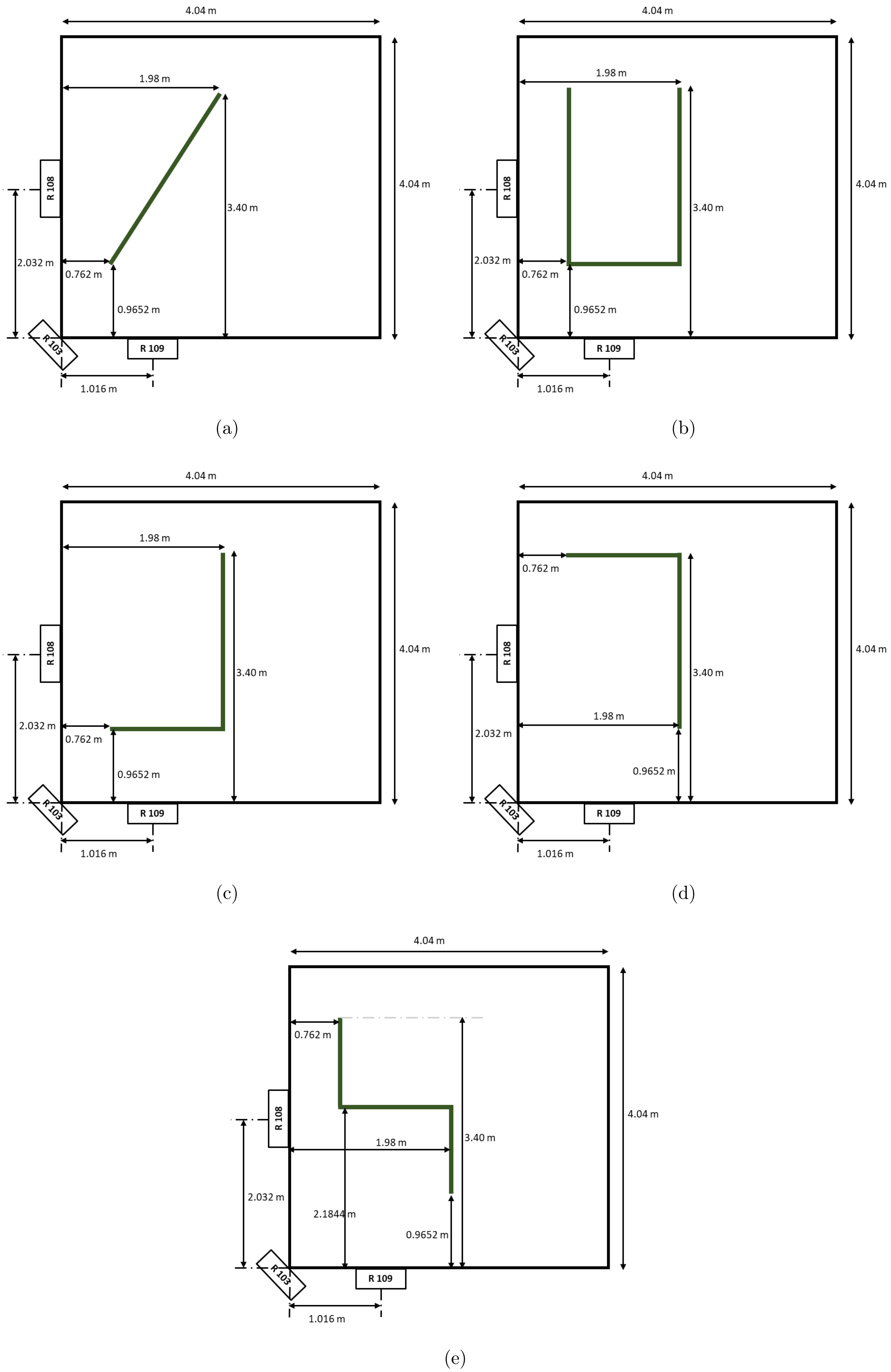


Figure 8: illustrates Room maps for walking in pattern (a) diag (b) U (c) gamma (d)L (e)four