

## Week 3 Report

This week I looked at several papers regarding mmWave radar.

The first paper I looked at was “High Precision Human Detection and Tracking Using Millimeter-Wave Radars by Han Cui, Naim Dahnoun, University of Bristol”.

This is the first paper I believe to be published by the University of Bristol that covers the topic of millimetre wave radar. The paper focuses on human activity recognition HAR and explores how millimetre wave radar can be used as a privacy oriented alternative to other more established privacy invasive methods such as the use of cameras and computer vision.

The paper starts by exploring related work and the previously used sensors and methods in the field of HAR such as camera based, depth camera based, Doppler radar, ultrasonic detection, Wi-Fi sensors and wearable devices using accelerometer and GPS data.

The paper then goes on to explain the theory behind millimetre wave radar, how it works and in what formats data coming from the radar can take. These formats for the IWR1443 mmWave module are raw adc data or processed data from the user programmable on chip data processor chain with a popular form of processed data being x-y-z object data.

A software framework for interfacing with the radar and performing post processing was created in Python and comprised of three main parts a radar handler; responsible for connecting to the serial ports and extracting the data from the radar module as well as sending configuration and command data to the module. A frame processor; that takes the data from the radar handler and makes sure all frames for task are in the same format. And a visualizer; that processes the data to create the final 2D or 3D output of the system.

The software is written in a way to take advantage of parallelism of the processing computer with each radar being assigned its own thread and the system working best on multi core systems where each thread has its own dedicated CPU core.

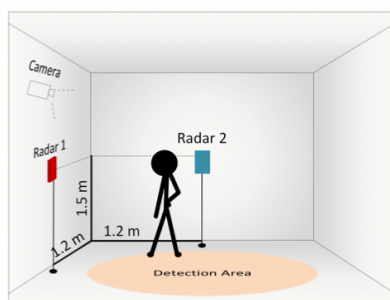


Figure 1

The system uses two radars positioned in a manner that gives two separate perspectives of the same area. A camera is placed by one of the radars in order to provide a ground truth for comparison of results at the end of the experiment. This setup can be seen to the left in Figure 1.

The data from the two radars come in the form of a point cloud with x,y and Z coordinates these point clouds are processed by the software framework to locate objects within each radar's field of view. These objects in the differing fields of view are then compared and any overlapping objects

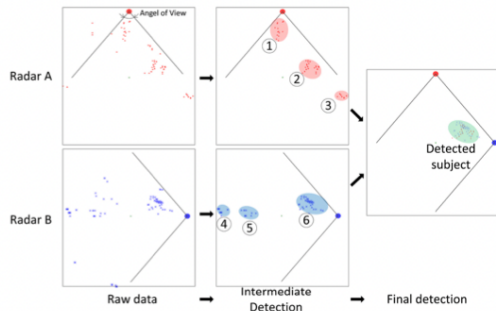


Figure 2

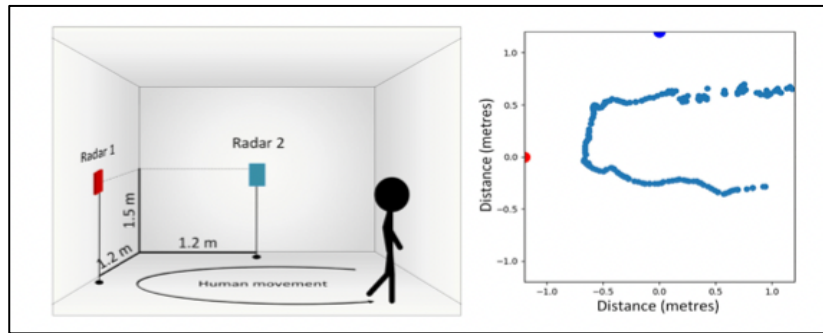


Figure 3

The paper then goes on to explore the effect of noise in system as more radars are added. It concludes the probability of interference is low less than 1% for a system using 4 radars and less than 5% for one with 10 radars. It also explains this interference is able to be reduced if the radars are synchronised or an interference detection algorithm is used.

	Sensitivity	Precision
One radar	96.4%	46.9%
Two radars	90.4%	98.6%

Table 1

Sensitivity and precision metrics are used to compare the use of 1 radar to the use of 2 in the system. With sensitivity being the ability to detect humans when they are in the area of detection and precision being the ability to distinguish humans from false detections. Table 1 presents the results found in the paper with a single radar having high sensitivity of 96.4% but a low precision of 46.9% meaning roughly one of two detections thought to be a human was not actually a one. The use of two radars drastically improves this precision to 98.6% this increase however comes at a cost of a small loss in sensitivity which means now every 1 in 10 times a human is present in the area of detection they are not detected by the system.

The paper then explains that a limitation of the system is the ability to distinguish multiple people at short distances such as people in a queue as they may obscure one another It also states that for two radars the effective area was a 2.4 by 2.4 metre region and explains that this region could be expanded by adding more radars into the system.

The second paper I looked at "A REAL-TIME AND HIGH PERFORMANCE POSTURE ESTIMATION SYSTEM BASED ON MILLIMETER-WAVE RADAR by Daniel Nickalls, Jiacheng Wu

and Naim Dahnoun” uses a single millimetre wave radar fixed above a single person in order to determine whether they are standing sitting or lying down.

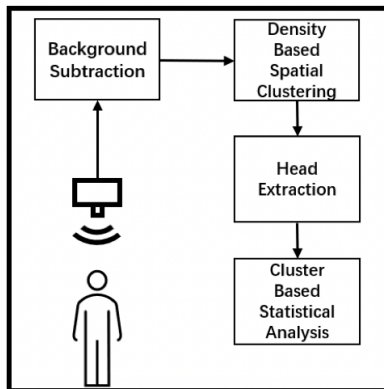


Figure 4

The way the system works is by first taking the data from the radar and filtering out the background focusing on the set region of interest of 1.4m x 0.7m x 2.35m. The system then takes this pre-processed data and uses the DBSCAN (density-based spatial clustering of applications with noise) algorithm in order to identify clusters in the three dimensional data set. An example of this process data can be seen in figure 5. After the data has been clustered the head cluster can be identified and the height can be calculated.

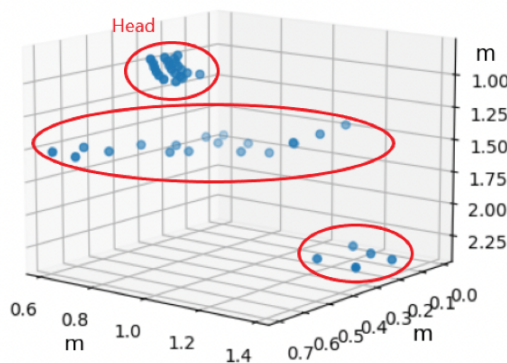


Figure 5

A decision tree model is then trained on this data to classify the posture. The architecture of this decision tree can be seen in figure 6.

In parallel to the decision tree model a computational neural network based on other research was also designed. this computational neural network was then fed the same data set in order to compare the decision tree approach with.

	Accuracy	Processing time	Training time
CNN	99.3%	0.82 s	36.5 s
Our system	99.1%	0.13 s	15.7 s

Table 2

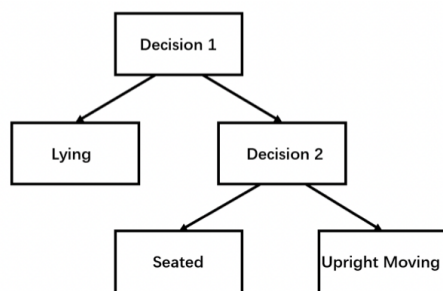


Figure 6

The results of both systems can be seen in Table 2 the system proposed in this paper has an almost identical accuracy to the computational neural network system however both the processing and training time are greatly reduced this is advantageous as it means this system can more easily deployed on a low cost an embedded system.

The 3rd paper titled “A Novel High Performance Human detection, Tracking and Alarm System Based on millimeter-wave Radar by Jiacheng Wu, Han Cui and Naim Dahnoun” builds up on the work presented in the past two papers. It combines the positives of both previous works and creates a single unified system capable of both human detection and tracking as well as posture estimation.

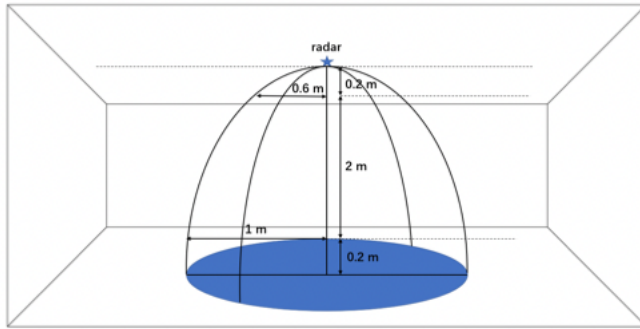


Figure 7

This new system uses a single IWR1443 millimetre wave radar placed on the ceiling of a room. The detection area of the system is suitable for a small room and this area is shown in figure 7. This detection area was determined by moving a 20cm cube around under the radar and recording the points at which the radar no longer discovered the cube.

Software wise the system combines the approaches found in both previous papers to create a system capable of both human detection and tracking as well as posture estimation. The system can be implemented as an alarm to detect unauthorised people entering its' field of view however when used in such a way more strict clustering parameters need to be used in order to reduce the number of false alarms these changes do result in the loss of some details of the person however in such an application this information is not so relevant.

The system was compared in different configurations for both detection and tracking as well as posture estimation and the results are summarised in the two tables below.

	Sensitivity	Precision
Baseline	96.4%	46.9%
Two-radar system	90.4%	98.6%
One-top system	97.1%	95.2%

Table 4: detection and tracking

	Standing	Sitting	Lying
Baseline	92.5%	92.3%	82.6%
One-top system	93.7%	93.1%	92.5%

Table 5: posture estimation

The combined system using a one top radar placement improves the sensitivity for tracking and detection considerably from the sensitivity in the first paper and it does this with only a small compromise to precision, it also achieves these results with only one singular radar, this increase is likely a result of the closer distance of the subjects to the sensor in the one-top system as the distance in this configuration is likely going to be around a meter in comparison to the original side placement where subjects are likely going to be up to 2 meters away from the radar. This one top solution is also advantageous as it can better deal with the downsides present in the first paper regarding people standing close together and people blocking view of other people.

The fourth paper I read titled "Real-Time Short-Range Human Posture Estimation Using mmWave Radars and Neural Networks by Han Cui and Naim Dahnoun" achieves much more detailed posture tracking, producing a wire frame model of the subject's posture as opposed to just classifying them into one of the three categories of lying, sitting or standing as was achieved in previous papers.

This new system uses a neural network in order to capture a person's posture this is a much more computationally demanding approach in comparison to those used the previous three papers I have looked at in this report however it gives us a lot more data about the persons posture which greatly increases the possible use cases of such a system for instance a system like this could find its use in the gaming sector where technologies such as virtual

reality are becoming quite popular and methods of accurately tracking a user's movements are in high demand.

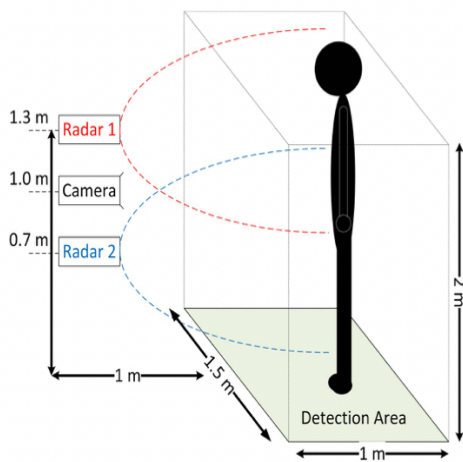
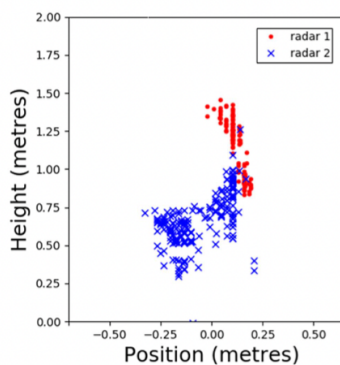


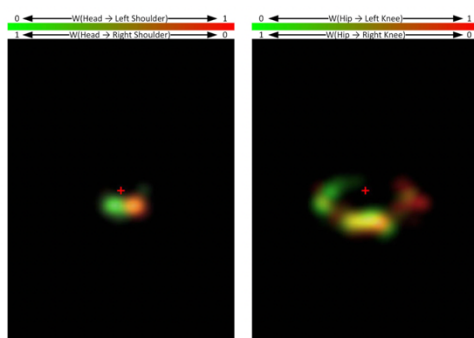
Figure 8

The setup used for this approach can be seen figure 8. It uses 2 radars to capture the whole body and a camera in order to record the ground truth which is used for evaluation of the system. The radars have an overlapping detection region. The radars produce 3d point clouds however the xy positions obtained were found to be more accurate than the depth measurements therefore the depth can be discarded with little consequence. This flattens the data to create a 2D image which can be more easily processed by a traditional CNN model. Figure 9 shows an example of the two-dimensional data.



The neural network was split into two components a part detector concerned with locating and extracting location of each joint and a spatial model concerned with refining the joint position considering the relative positions of other joints and previous joint positions. The neural network was created using TensorFlow and Keras.

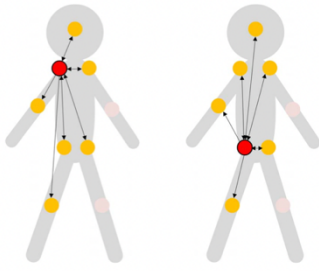
Figure 9



The part detector works by taking the image like that seen in Figure 9 and producing a heat map that represents the possible positions of particular joints an example of such a heat map can be seen in figure 10.

Figure 10





The spatial component deals with deciding where specifically to place the joints, the model considers the positions of other joints a dependency graph representing these considerations for the left shoulder and left hip can be seen in figure 11.

Figure 11

There is also a temporal part that looks at the temporal correlation and improves the estimate of the position by restricting the maximum displacement of the joints from frame to frame.

This refining of the estimates improves the accuracy of the system as can be seen in figure 12 the part detector on its own does a good job of locating the head however joint estimation gets worse as you go down the body. After being fed through the special model the estimate improves drastically.

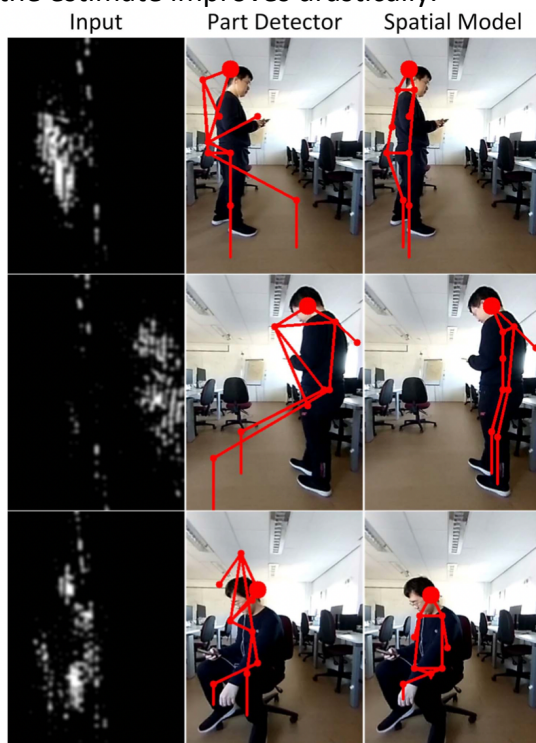


Figure 12

The Paper then compares its system to similar systems using different technologies the results of these comparisons are summarised table 6. The results in Table 6 represent the localization error of the systems meaning how far out was the joint in reality from the predicted position provided by the system.

	Method	AP (OKS=0.5)	AP (OKS= 0.5:0.95:0.05)	MLE (cm)
<b>Our work</b>	<b>mmWave</b>	<b>0.959</b>	<b>0.713</b>	<b>12.2</b>
HRNet [2]	Camera	0.928	0.782	NA
UDP-Pose [19]	Camera	0.949	0.808	NA
RF-Pose2D [20]	RF	0.933	0.624	NA
RF-Pose3D [13]	RF	NA	NA	4.0-4.9
mm-Pose [3]	mmWave	NA	NA	2.7-7.5
CLGNet [4]	mmWave	NA	NA	27.9

Table 6

From the data in Table 6 it can be seen the system does a great in job comparison to other techniques with the method used providing many advantages in areas such as privacy and detection in less ideal conditions such as through fog and low light conditions in comparison to camera-based methods. The system has a high processing speed and low cost in comparison to other systems.