Detection and Classification of moving objects with a 24 GHz fast chirp Radar for people counting applications

By
XXX ID:XXX

Supervised by
Prof. Dr. Andreas Becker, Daniel Bonney

Outline

1. Introduction
2. Walking pattern extraction
3. Test cases and results
4. System implementation
5. Summary

Section 1: Introduction

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1.1 Motivation

People counting

in shopping malls

in car accidents

1.2 Problem statement

Micro-Doppler effect

walking recognition

Signal processing

1.3 Research method

Test case driven experiments based on literature research

1.4 Radar module

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Specification (customizable)

	resolution	Max range
Range	0.6m,	38.4m
velocity	±0.49km/h	±31.5 km/h
angle	1 degree	50 degree

Carrier frequency	**24GHz**
Wavelength	1.25cm
Sweep bandwidth	250MHz
ADC sample frequency	366.3kHz
Number of samples per chirp	128
Number of chirps per measurement	128
Sweep period	354.9us

1.4 Radar module

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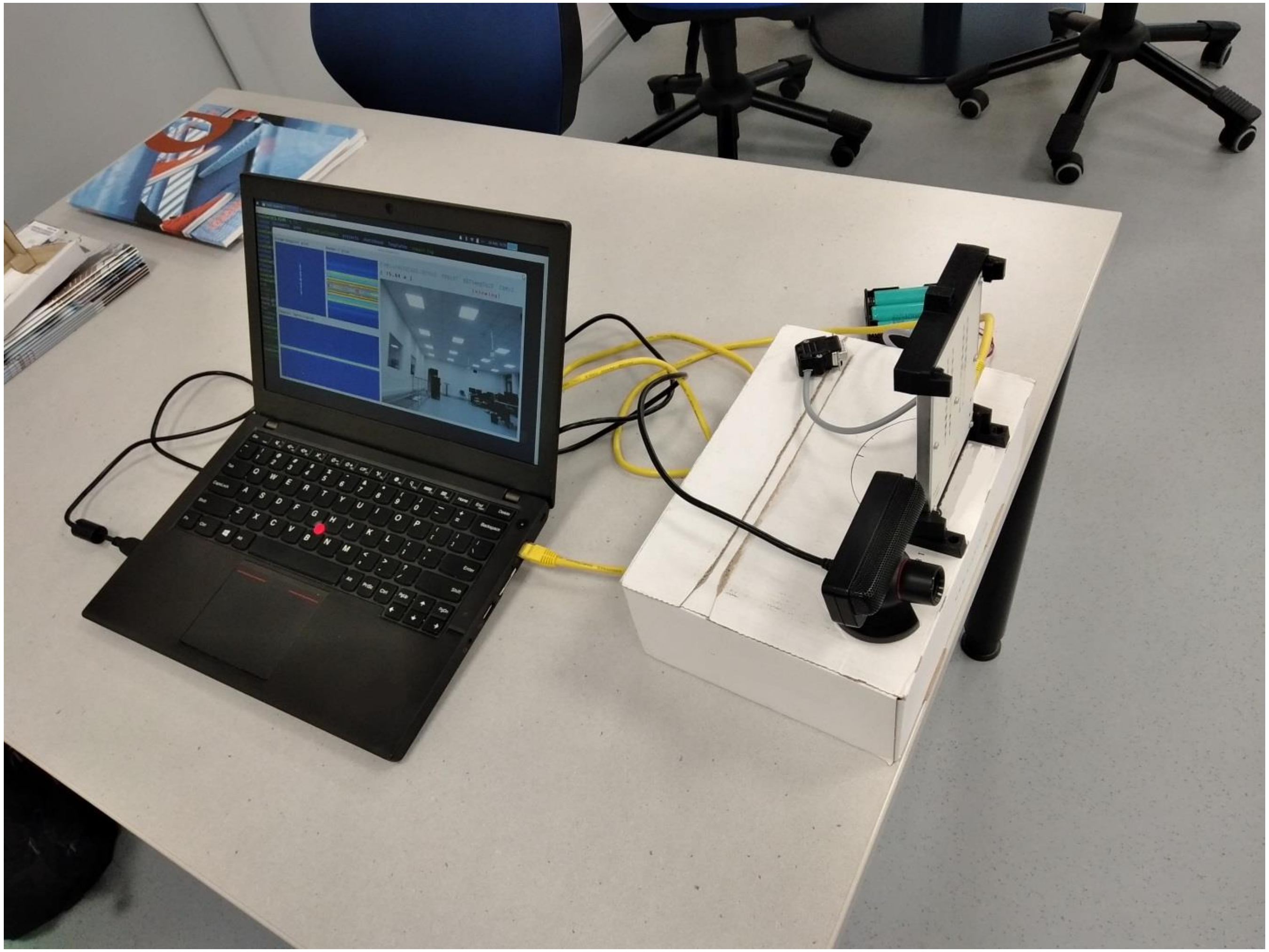
Setup



1.4 Radar module

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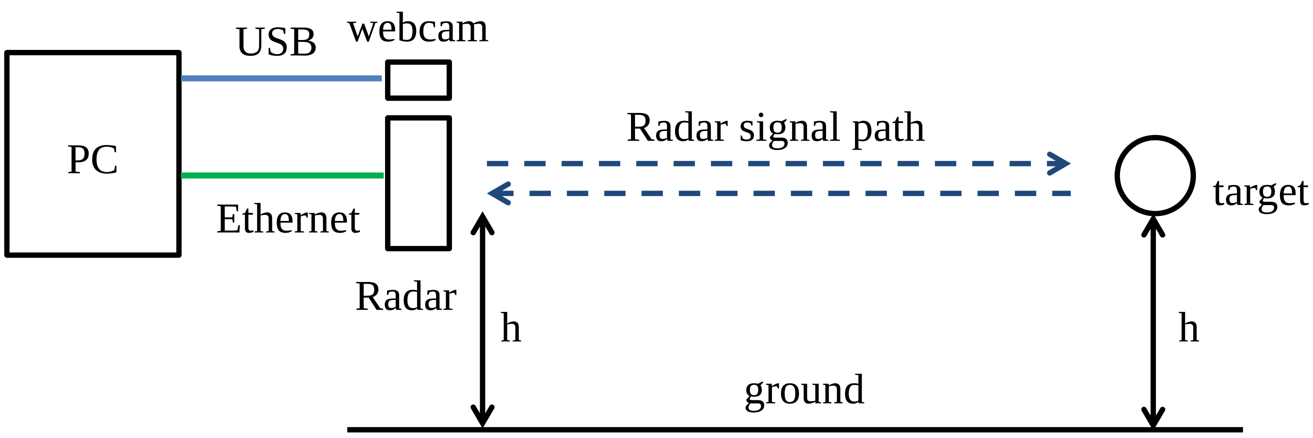
Setup



Signal recording: Ubuntu

Signal analysis: Matlab

System implementation: Ubuntu

Section 2: Walking pattern extraction

2.1 Signal preprocessing

2.2 Target tracking

2.3 Pattern sequence extraction

2.4 Feature sequence extraction

2.1 Signal preprocessing

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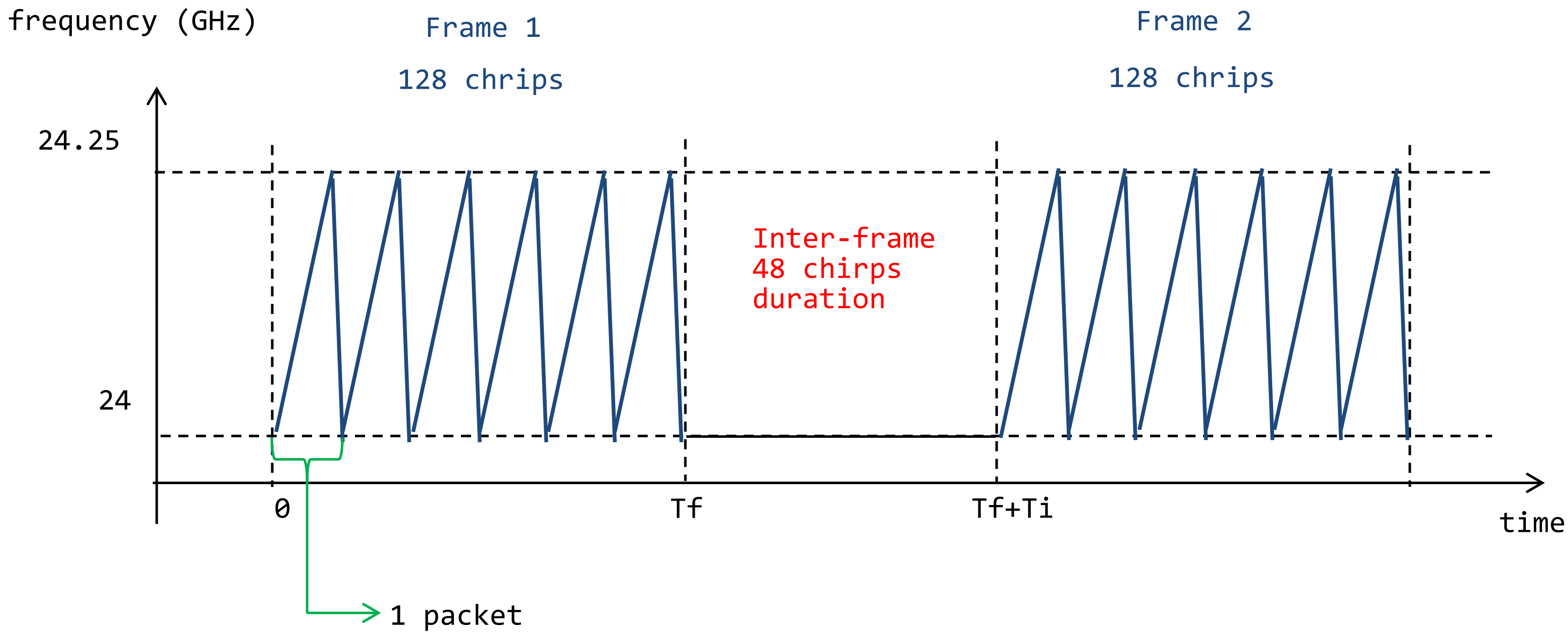
2.1.1 Initial processing

packet processing (fast chirp)

2D fft



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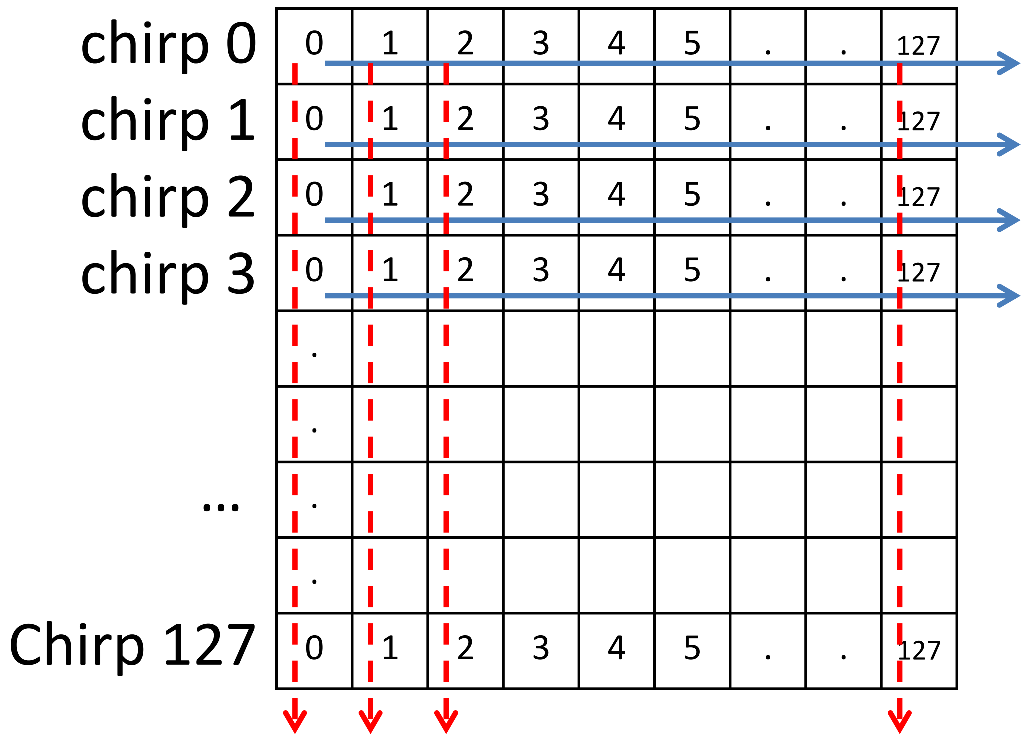
2.1.1 Initial processing

packet processing

2D fft



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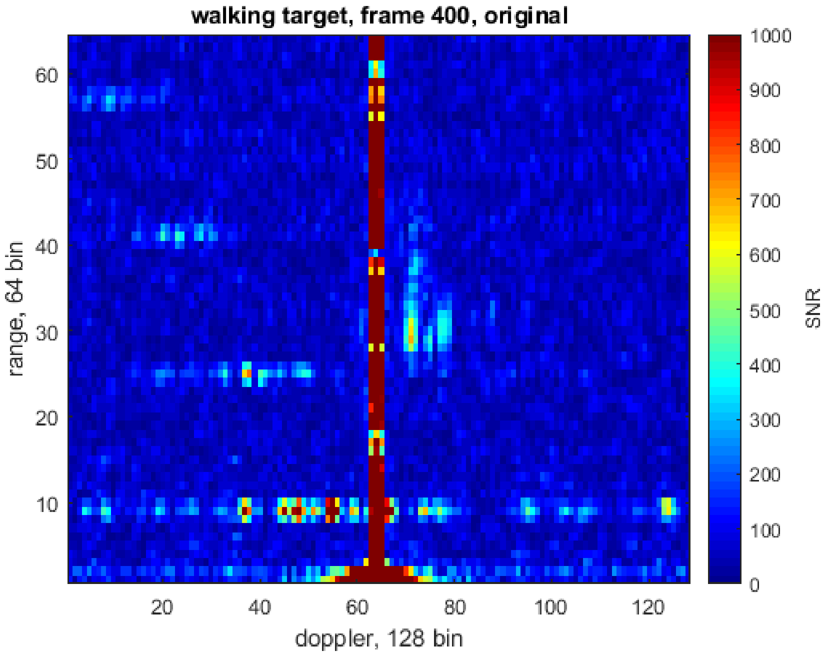
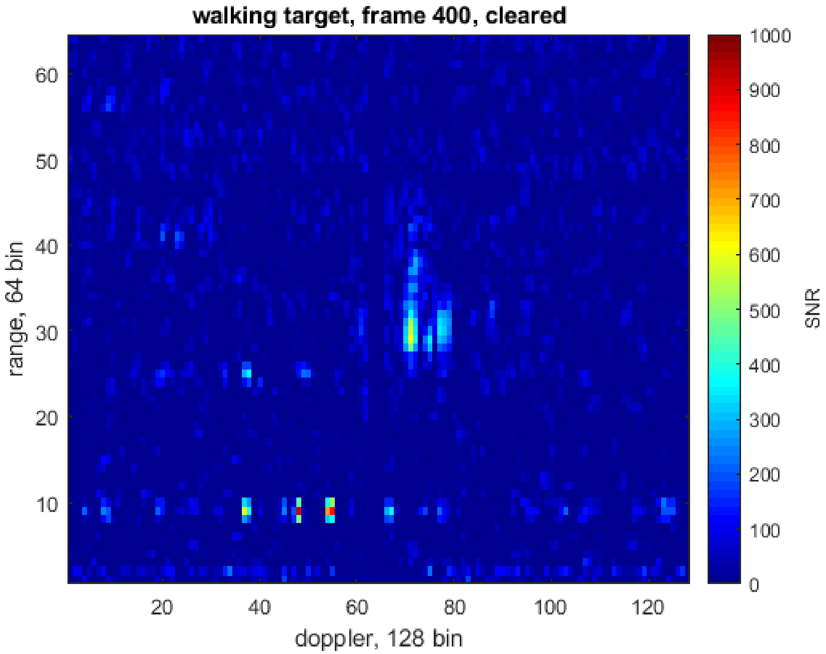
2.1.2 **Clutter removal**

stationary clutter

correlated clutter



before

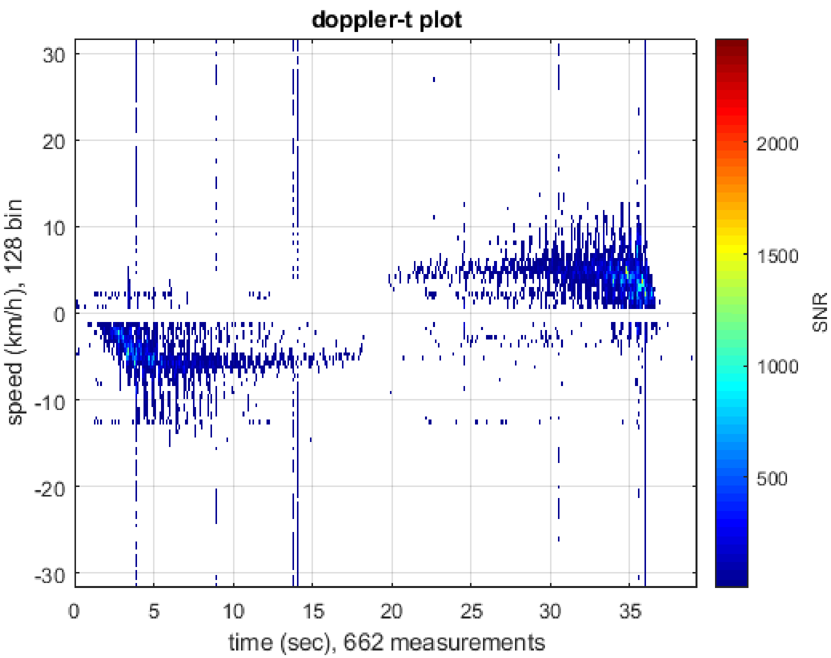


after

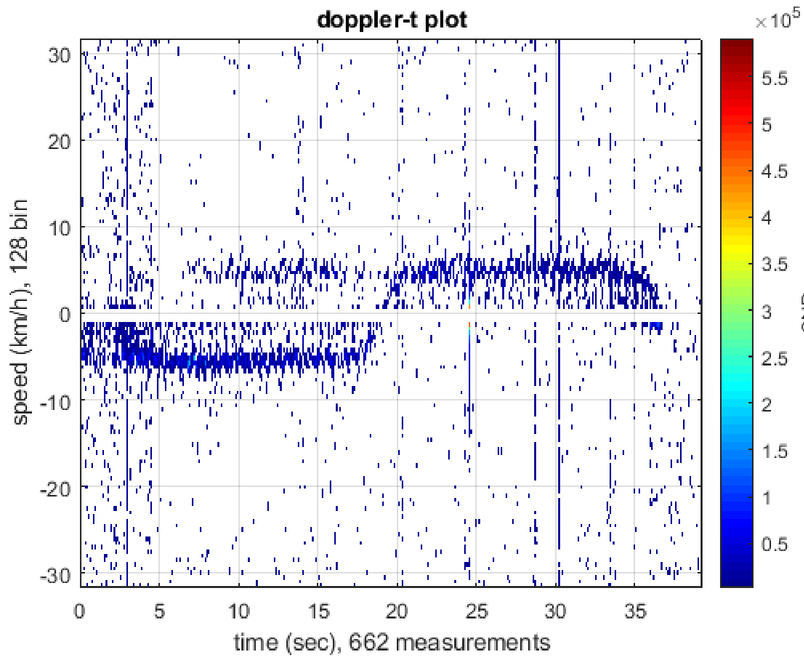
2.1 Signal preprocessing

2.1.3 **Weak signal enhancement**

the time gain method, $b_{r,d} = a_{r,d} \cdot r^k, k = 1,2,\ldots,n$



before

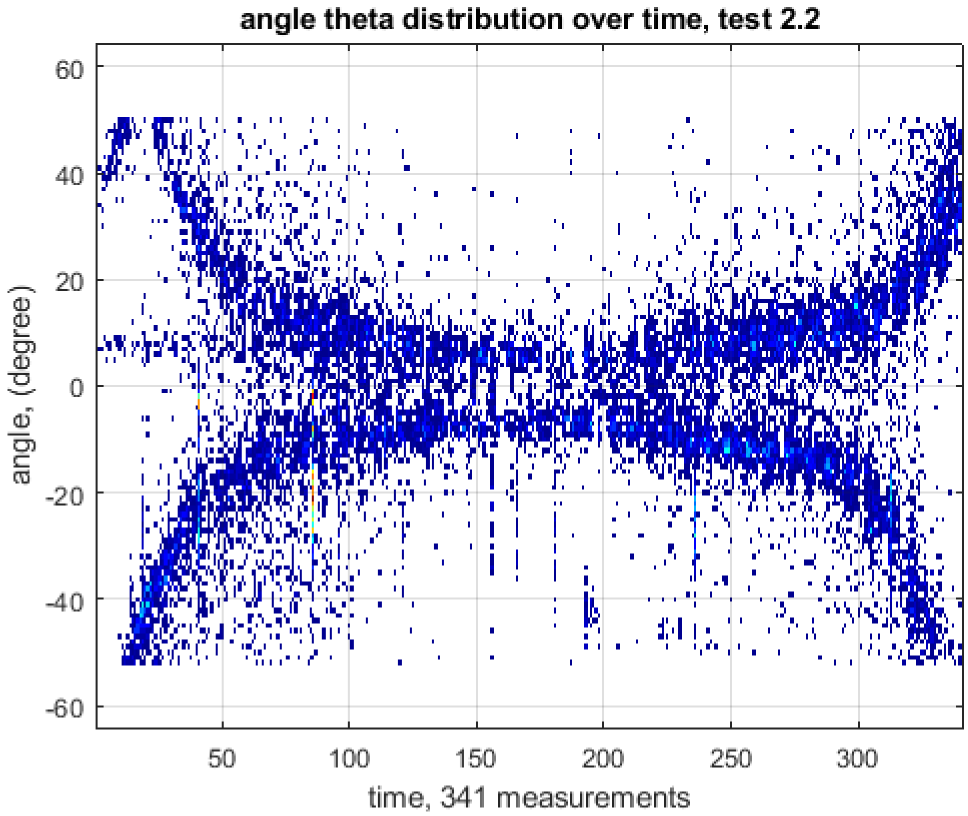


after

2.1 Signal preprocessing

2.1.4 **Signal detection**

angle pre-separation (2 person)



2.1 Signal preprocessing

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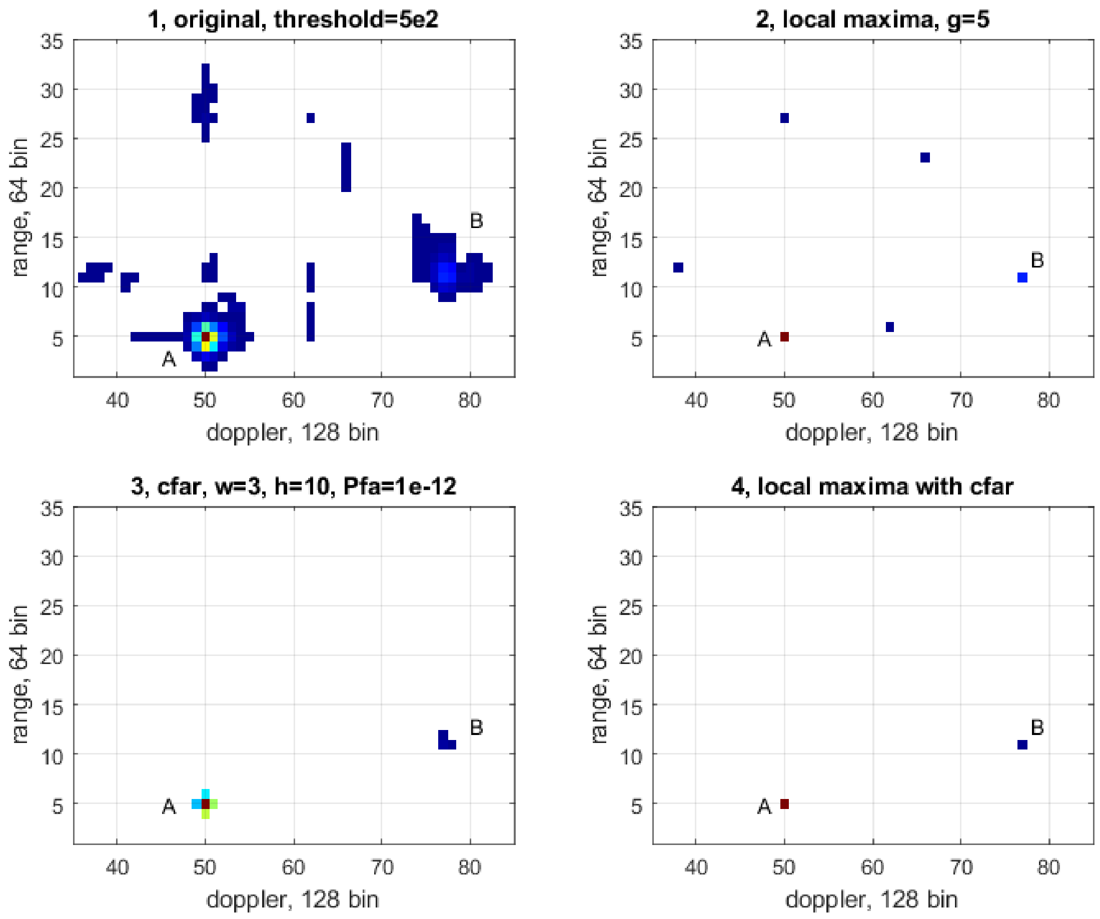
2.1.4 Signal detection

local maxima detector & CA-CFAR detector



2.2 Target tracking

2.2.1 Single target tracking

single track management

1, Calculate **Kalman prediction**

2, Polar to Cartesian conversion for all detection points.

3, Calculate **distance array** between detection points and prediction point

4, Remove outliner and noise points

5, Calculate **Kalman estimation** with the **closest detection**

6, Update current location

2.2 Target tracking

2.2.2 Multi-target tracking

track management

1, calculate **Kalman prediction** for all tracks

2, calculate **cost matrix**

3, apply **Hungarian algorithm** for assignment

4, calculate **Kalman estimation** for tracks with update

5, update current **track properties**

6, **remove tracks** in lost state and **initialize new tracks** for all detections with no assigned track

7, update **current location** of tracked target

2.3 Pattern sequence extraction

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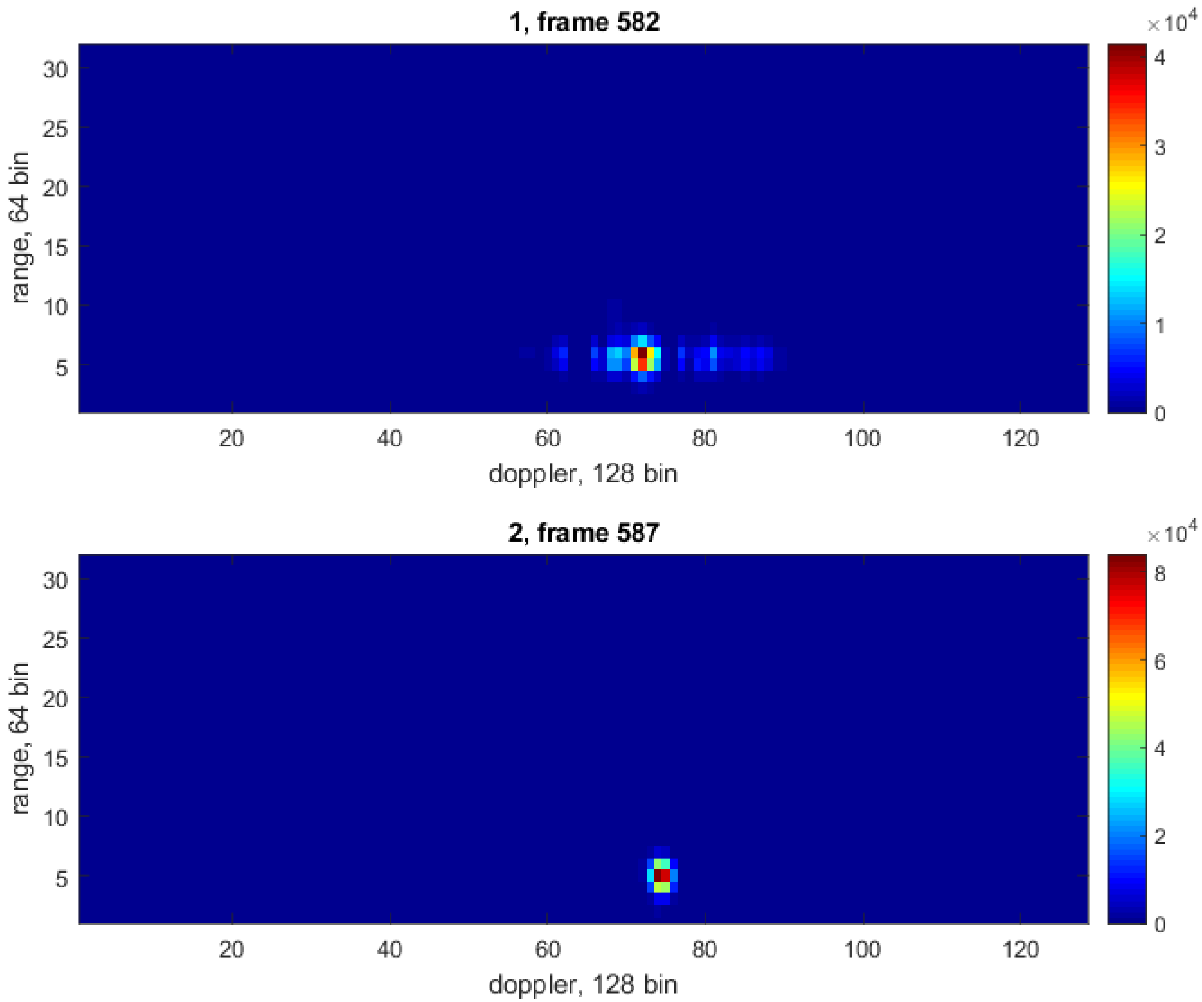
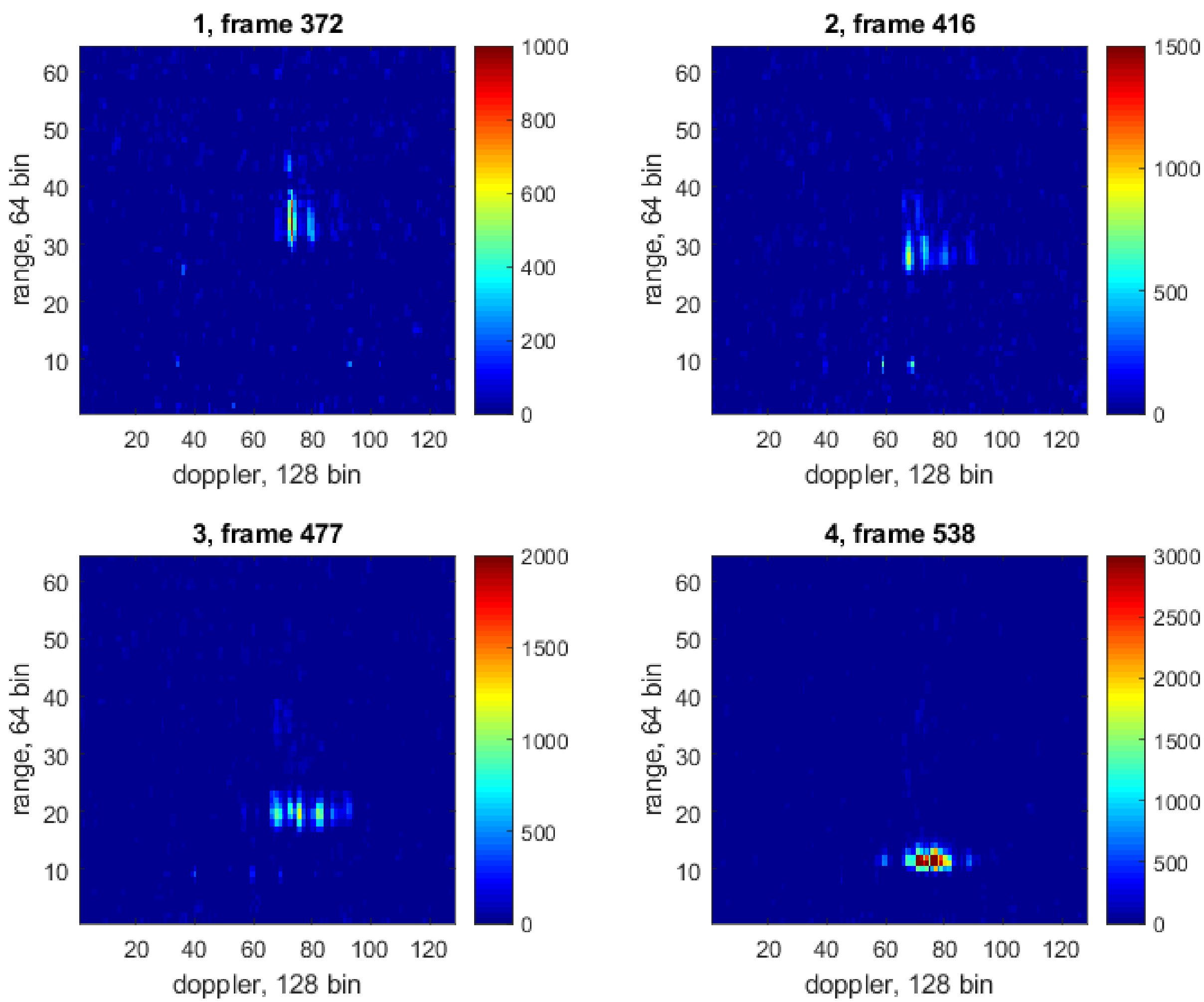
2.3.1 Range-Doppler profile ambiguity



2.3 Pattern sequence extraction

2.3.1 Range-Doppler profile ambiguity



2.3 Pattern sequence extraction

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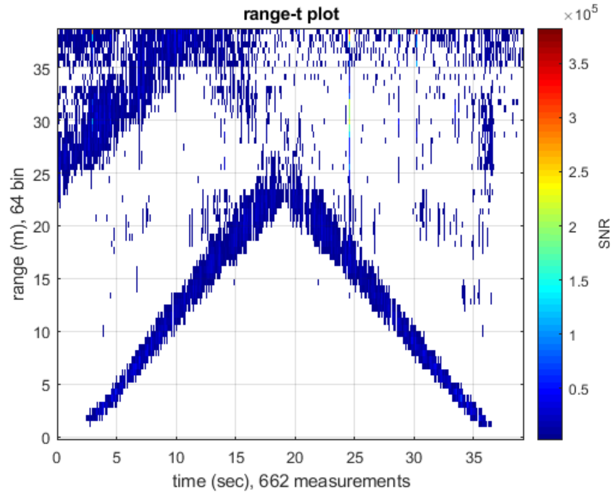
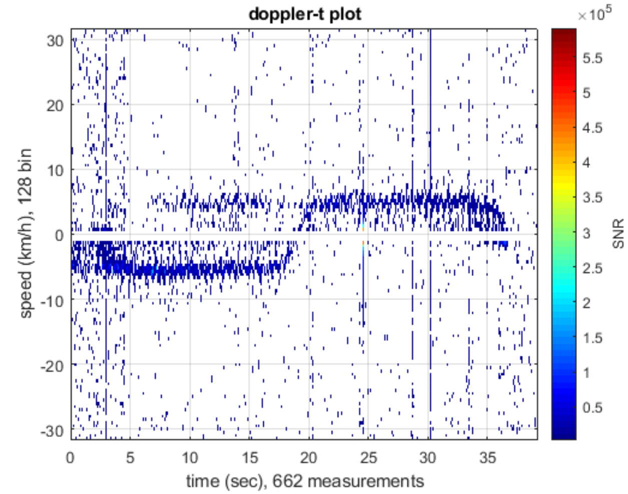
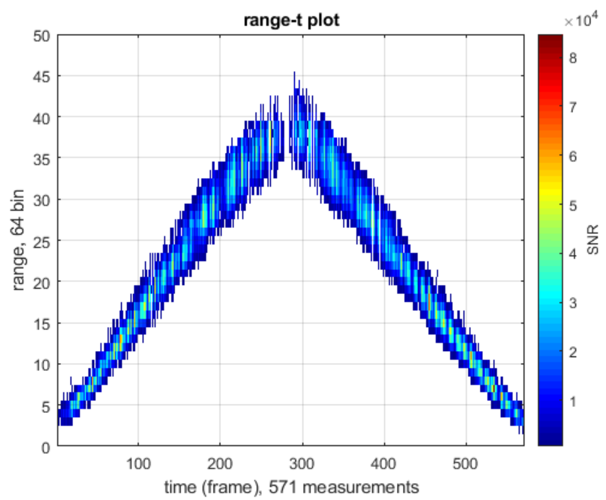
2.3.2 Extraction result using Kalman filter

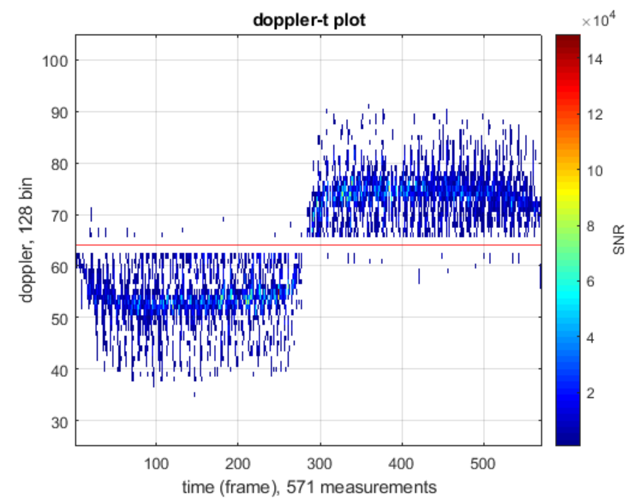
Th2 = 3e5





Th2 = 8e4





2.4 Feature sequence extraction

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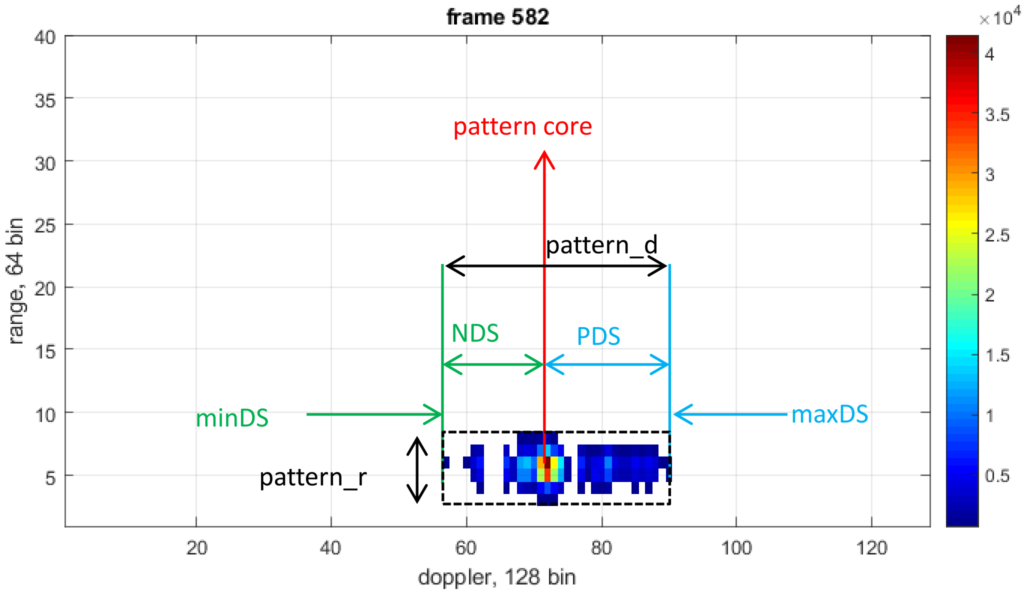
2.4.1 Feature definition

minDS (Minimum Doppler Spread): the Doppler bin minimum
maxDS (Maximum Doppler Spread): the Doppler bin maximum
NDS (Negative Doppler Spread): the maximal difference between minDS and core
PDS (Positive Doppler Spread): the maximal difference between maxDS and core



pattern_d: maximum allowed doppler profile

pattern_r: maximum allowed range profile

2.4 Feature sequence extraction

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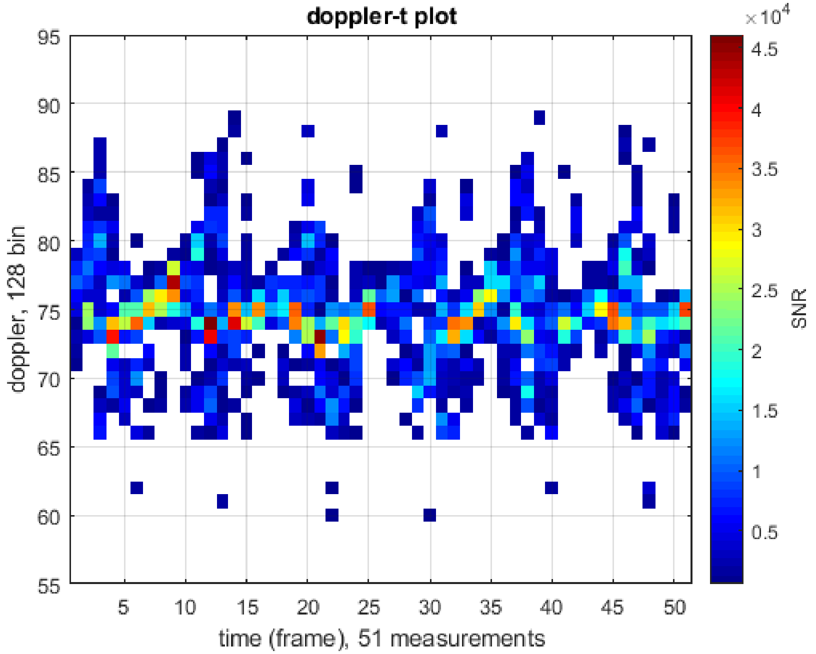
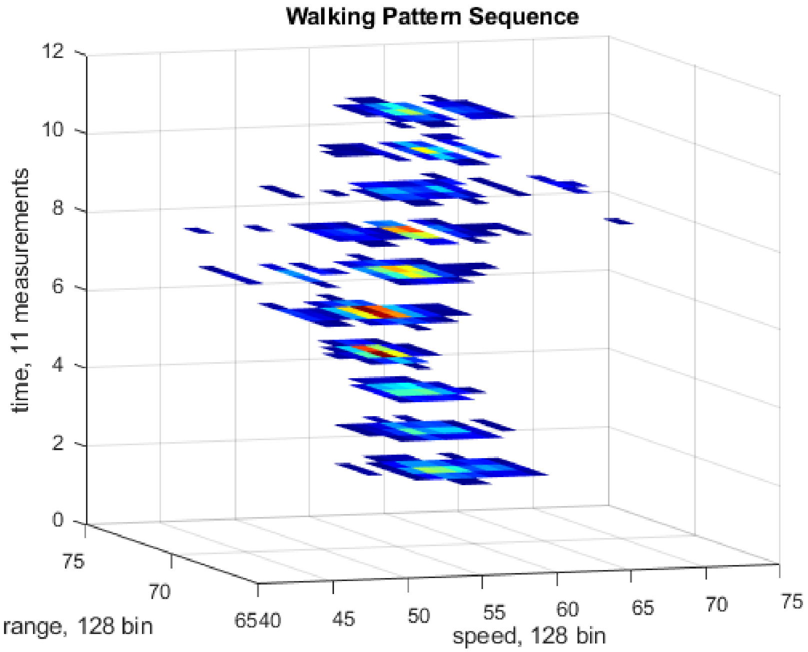
2.4.2 Original pattern sequence





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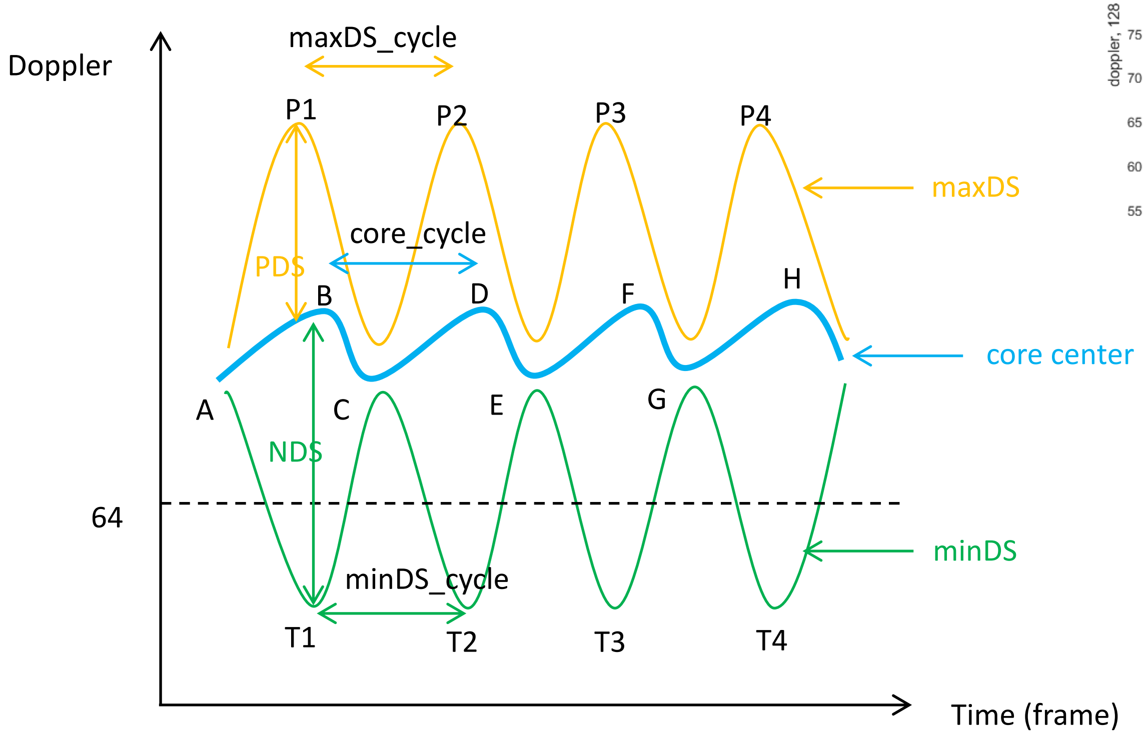
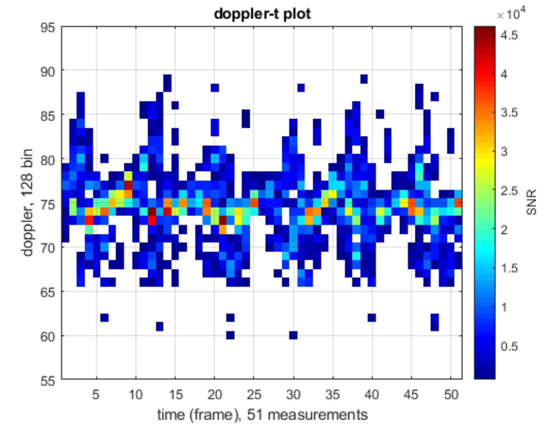
2.4.3 Simplified signal model





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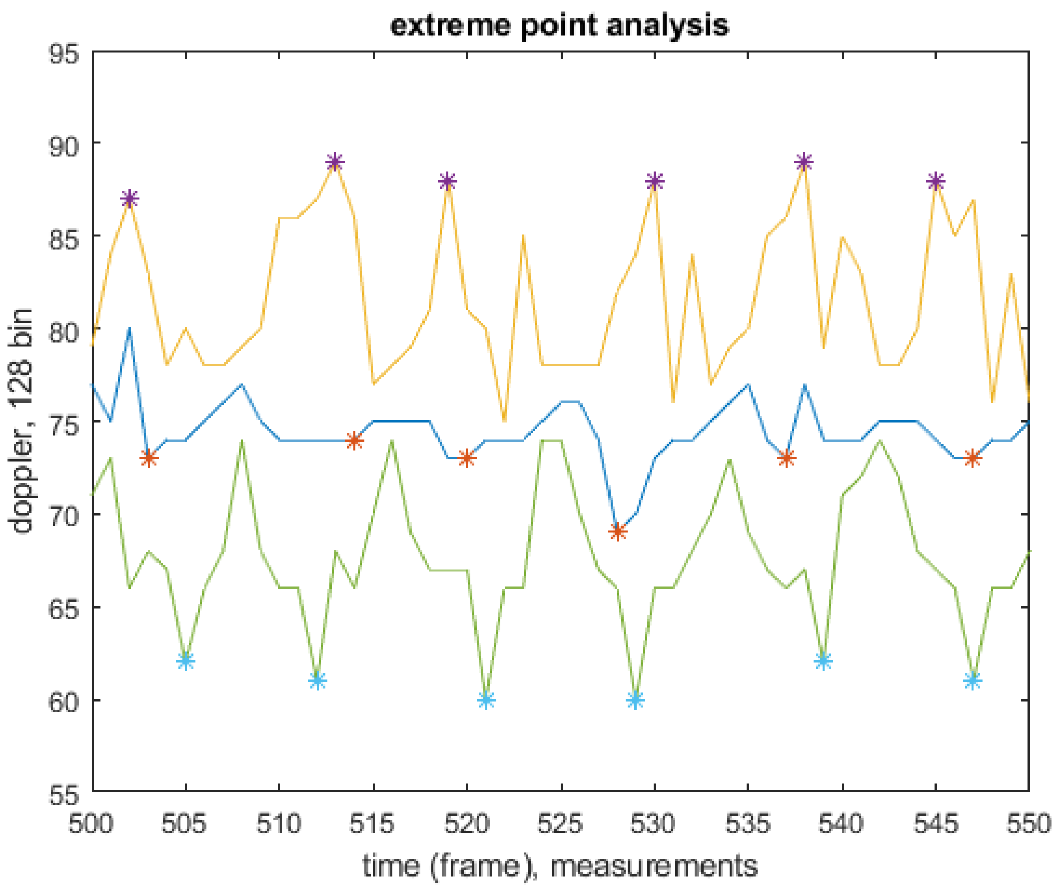
2.4.4 Online peak/trough extraction



2.4 Feature sequence extraction

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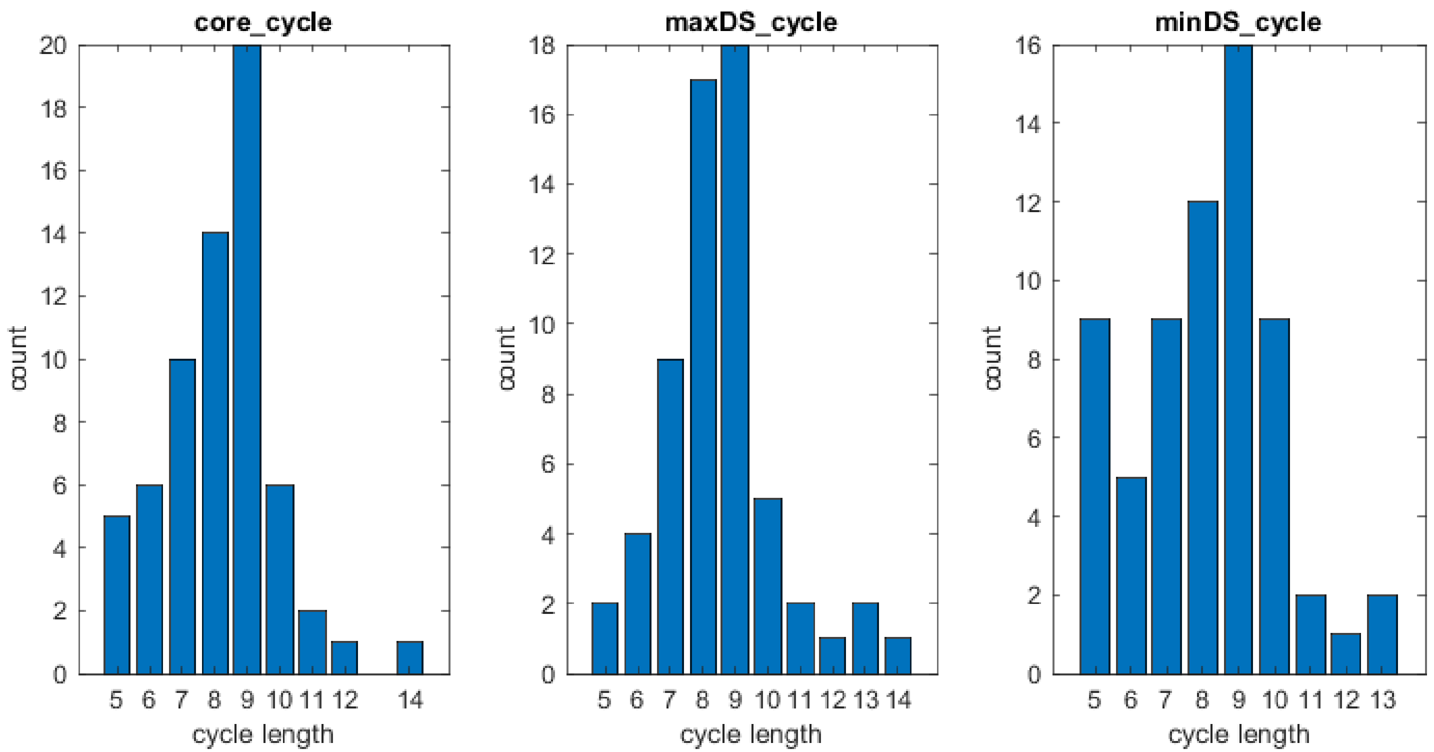
2.4.4 Online peak/trough extraction

cycle measurement of test 1.1



2.4 Feature sequence extraction

2.4.4 Online peak/trough extraction

proposed features

1, Pattern cycles: core_cycle, maxDS_cycle, minDS_cycle

2, Average walking radial velocity: walk_mean_v

3, NDS and PDS

4, Walking acceleration: walk_acceleration

Section 3: Test cases & results

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3.1 Test cases 1: test 1.1 – test 1.9

3.2 Feature analysis

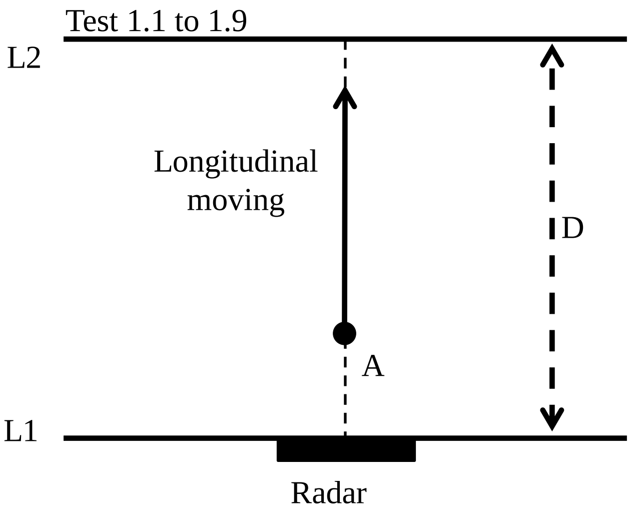
compare set 1-3

3.1 Test cases 1

Test 1.1 – 1.9

Scenario: One people walking (longitudinal and lateral)

Objective: Test basic measurement capabilities



3.1 Test cases 1

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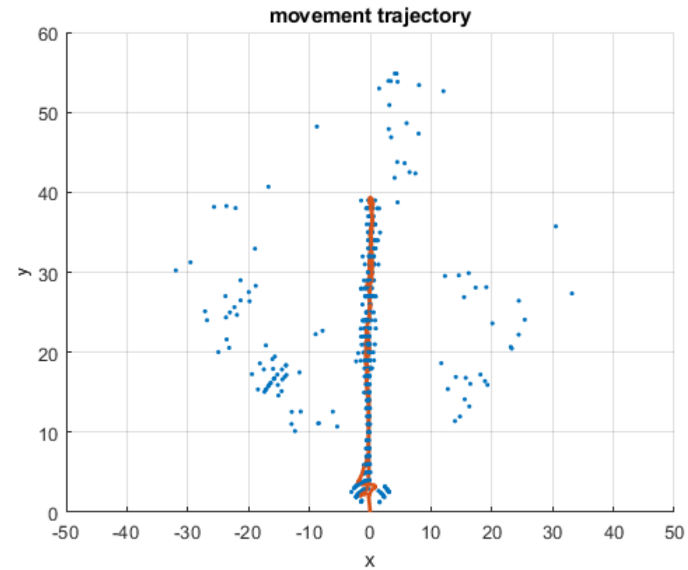
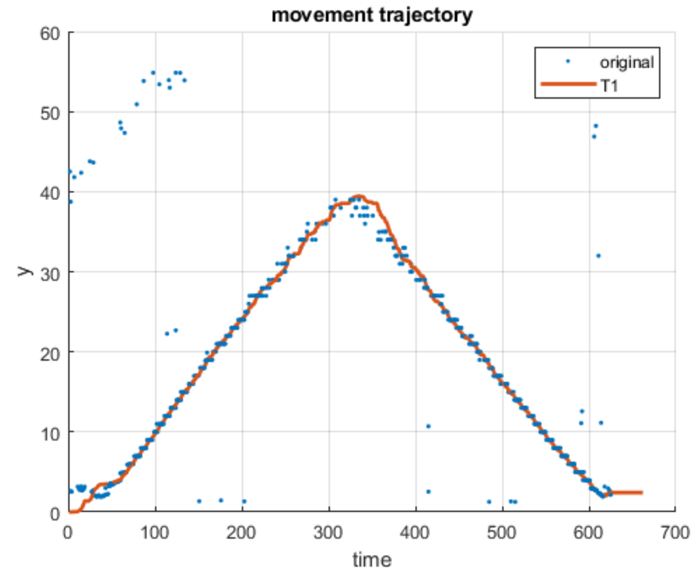
Test 1.1 tracking result





3.2 Feature analysis

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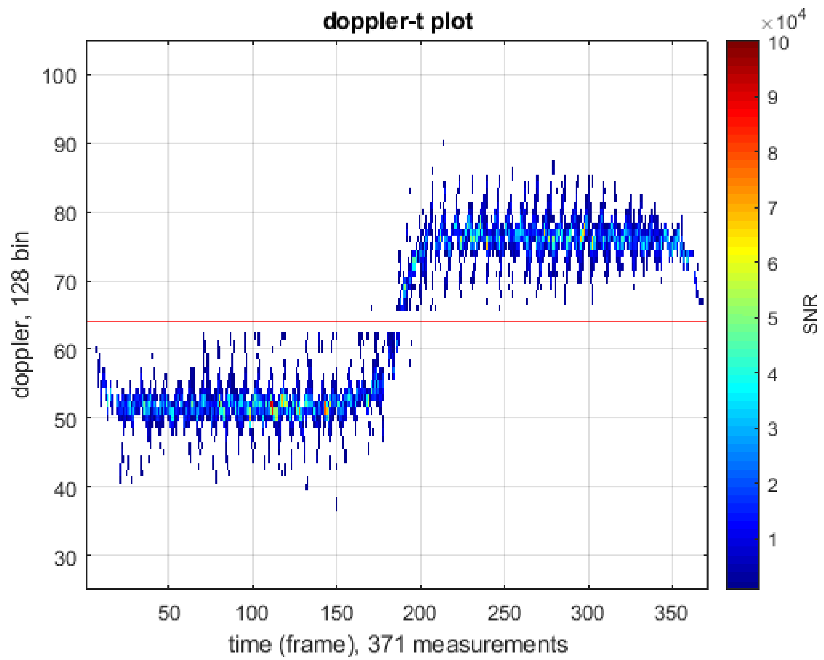
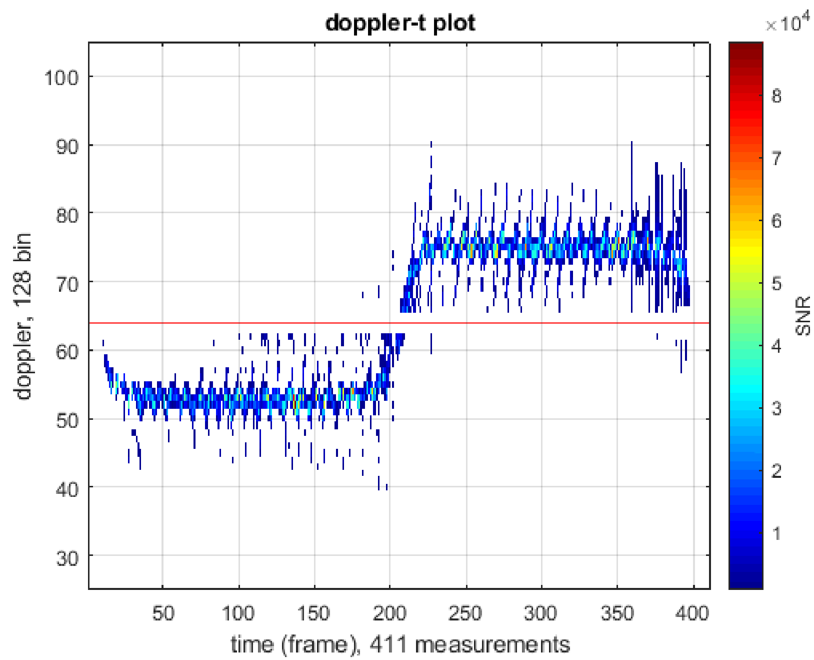
pattern sequences comparison test 1.2 and test 1.4



Casual walking



Hands in pockets

3.2 Feature analysis

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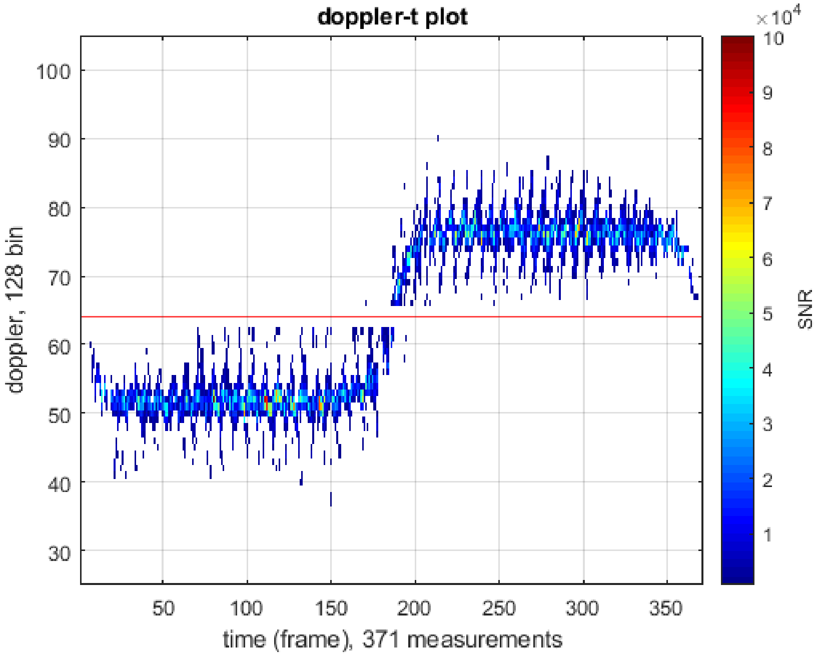
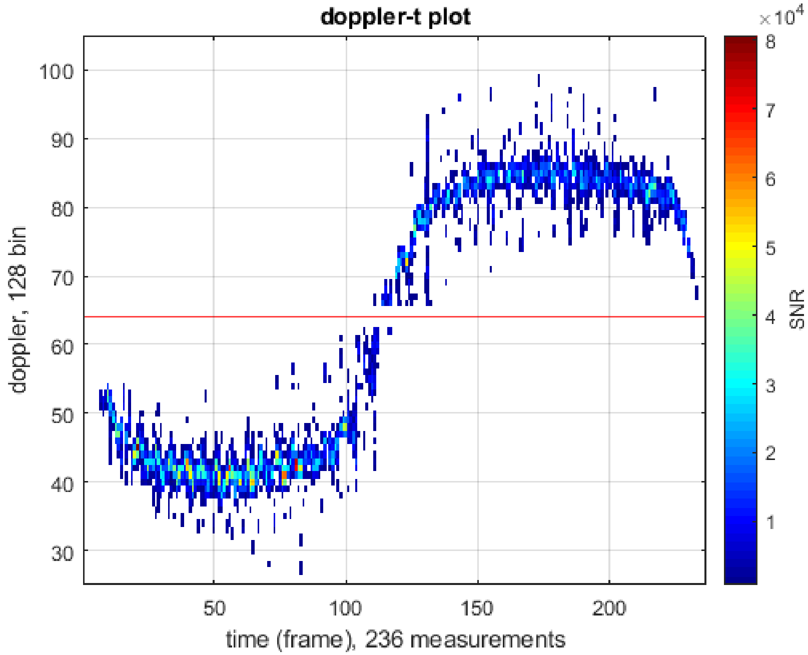
pattern sequences comparison test 1.2 and test 1.5



Casual walking



running

3.2 Feature analysis

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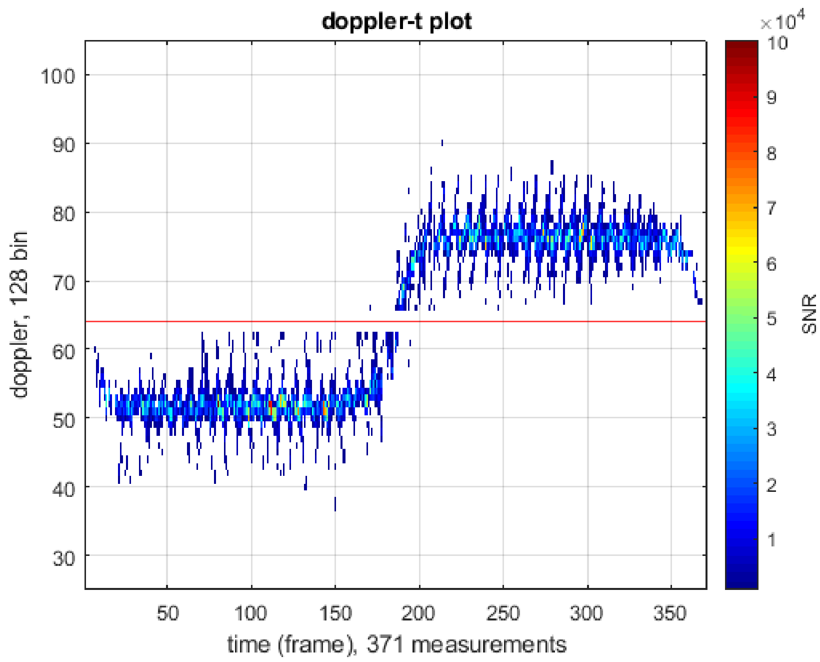
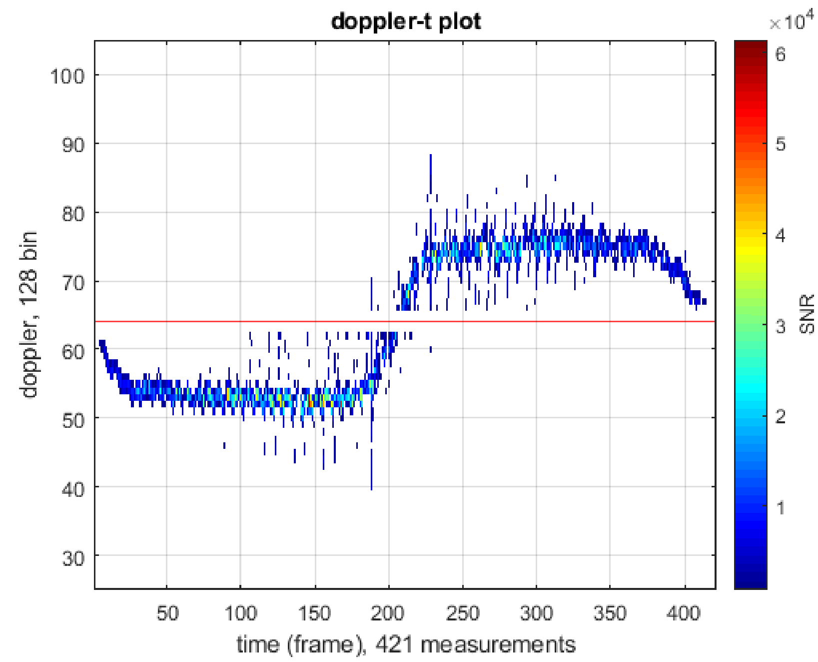
pattern sequences comparison test 1.2 and test 1.8



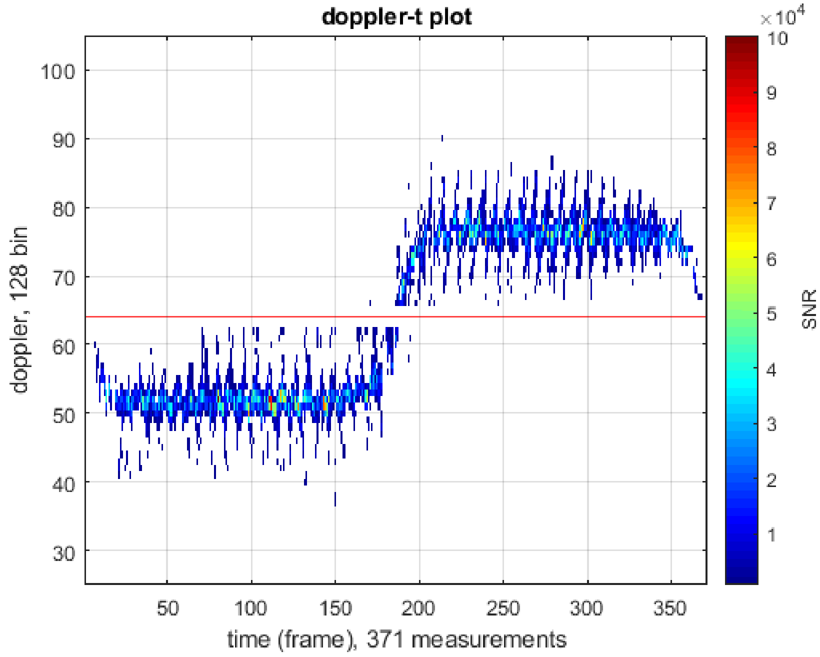
adult



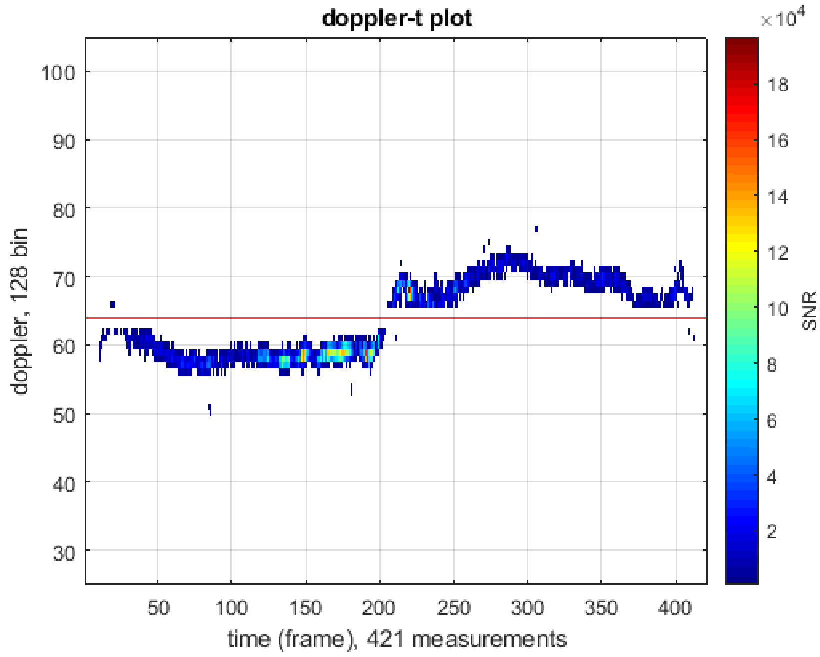
child

3.2 Feature analysis

pattern sequences comparison test 1.2 and test 1.9



adult



cart

3.2 Feature analysis

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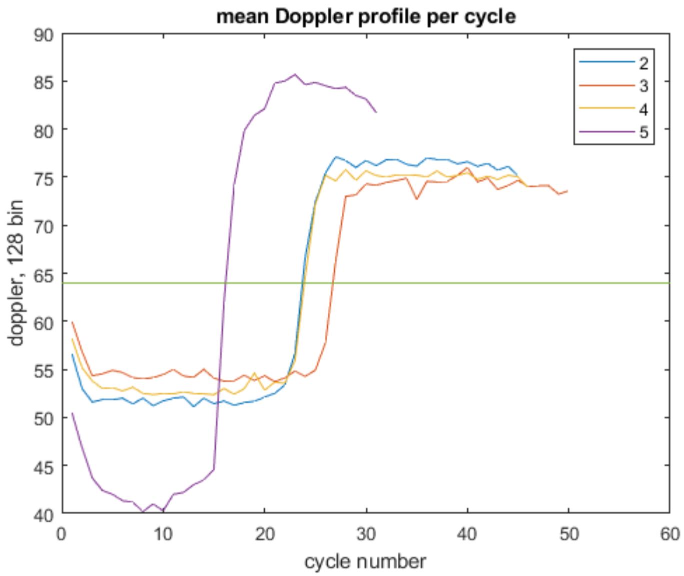
Compare set 1

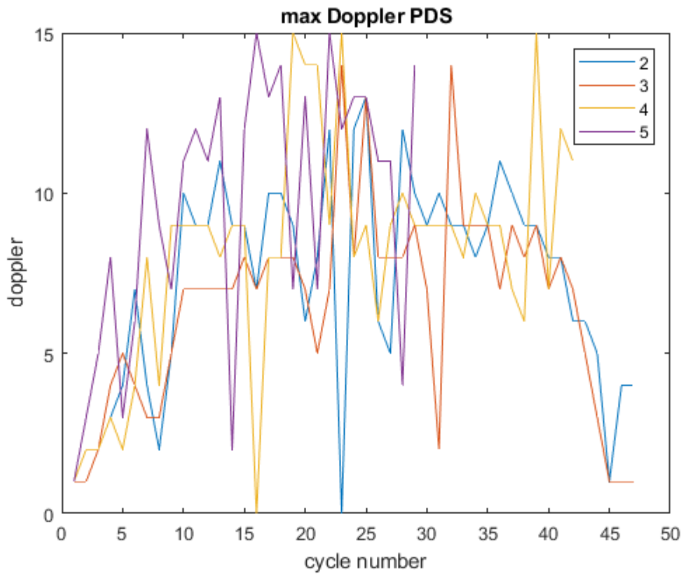
Test 1.2: person A is walking casually inside a tent.

Test 1.3: person A is walking slower inside a tent.

Test 1.4: person A is walking casually inside a tent with hands in pockets.

Test 1.5: person A is running inside a tent.





3.2 Feature analysis

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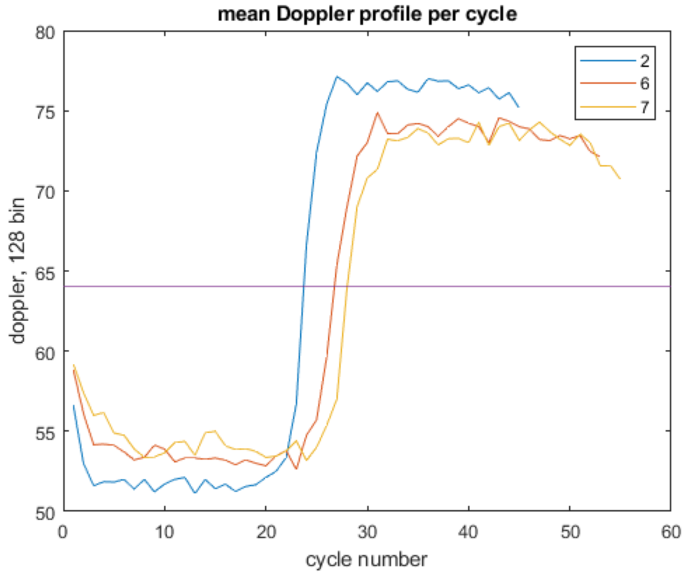
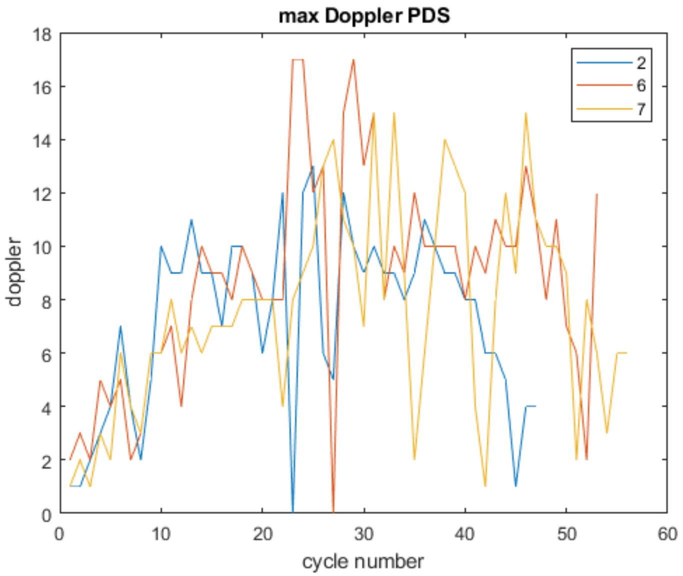
Compare set 2

Test 1.2: person A is walking casually inside a tent.

Test 1.6: person B is walking casually inside a tent.

Test 1.7: person C is walking casually inside a tent.





3.2 Feature analysis

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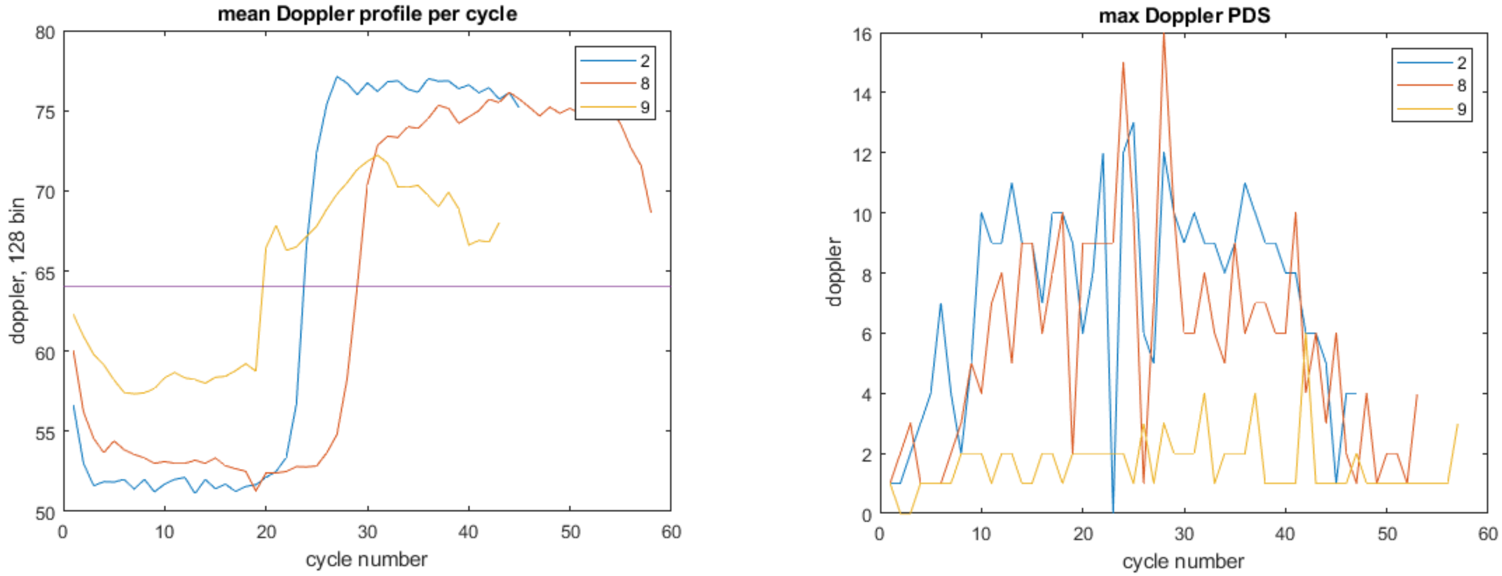
Compare set 3

Test 1.2: person A is walking casually inside a tent.

Test 1.8: person D (child) is walking casually inside a tent.

Test 1.9: person A is a moving cart tray in a lab.



3.2 Feature analysis

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Cycle measurement of all test 1

	Test	core_cycle	maxDS_cycle	minDS_cycle
	Test 1.1	8.1061	8.1194	8.0735
walk	Test 1.2	7.5556	7.3191	7.4255
	Test 1.3	8.3800	8.7174	9.2500
	Test 1.4	8.0435	8.7857	8.4750
run	Test 1.5	6.5667	6.8929	6.4545
	Test 1.6	8.2642	8.0189	8.3269
	Test 1.7	8.4000	8.0357	8.6346
child	Test 1.8	6.8621	6.9808	6.8571
cart	Test 1.9	8.7143	6.7719	7.2340
	Test 1.10	8.3676	8.0896	7.3788

3.2 Feature analysis

short summary

1, Pattern cycles: core_cycle, maxDS_cycle, minDS_cycle

walk/run, adult/child

2, Average walking radial velocity: walk_mean_v

walk

3, NDS and PDS

people/objects

4, Walking acceleration: walk_acceleration

not specific result

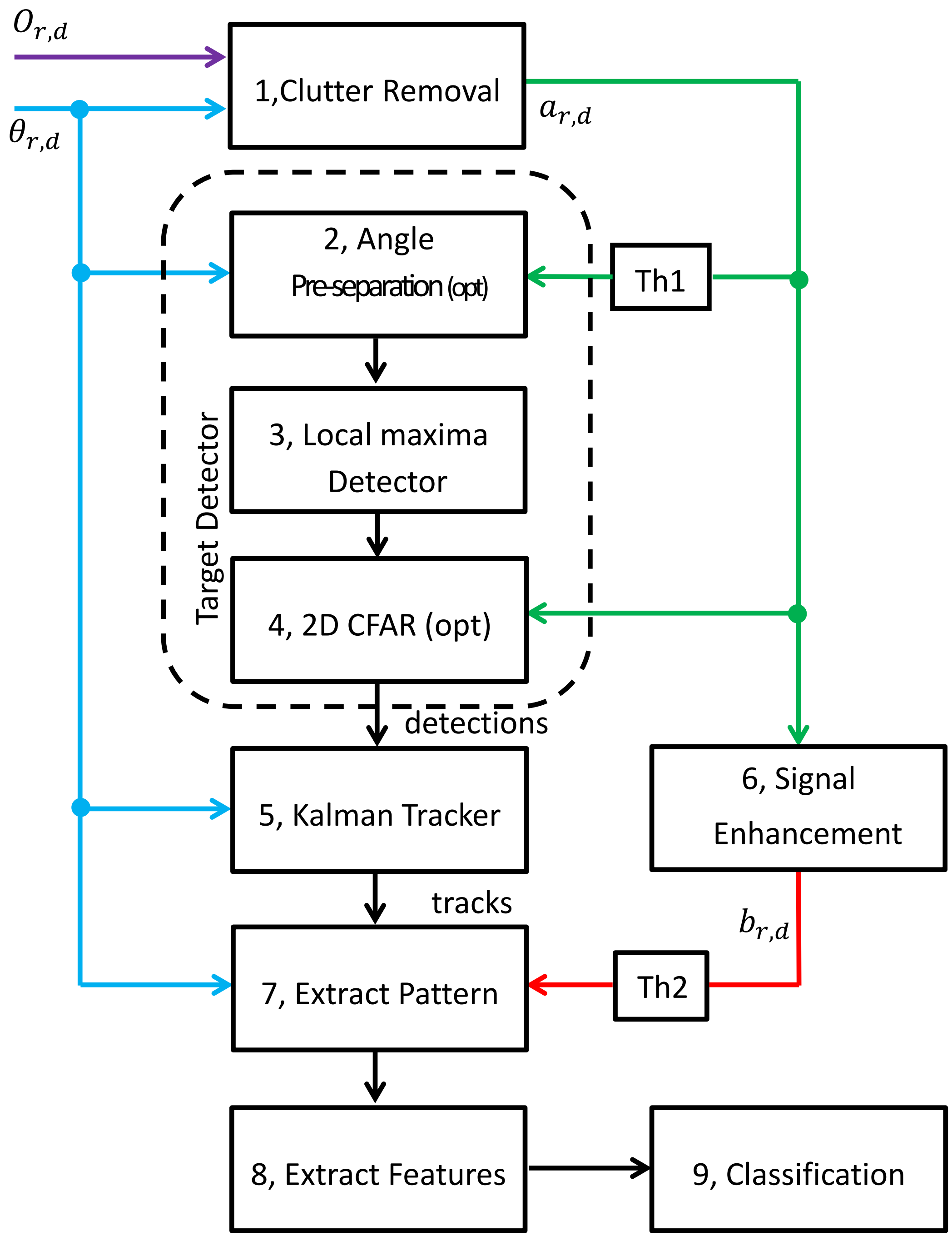
Section 4: System implementation

4.1 Signal processing blocks overview

4.2 Radar data recording tool

4.3 Live tracking tool

4.1 Signal processing blocks overview



4.1 Radar data recording tool

Application features:

1, visualize incoming radar signal

2, show pictures of FOV (field of view)

3, save incoming radar data and the photo of FOV

4, operate by key press

4.1 Radar data recording tool

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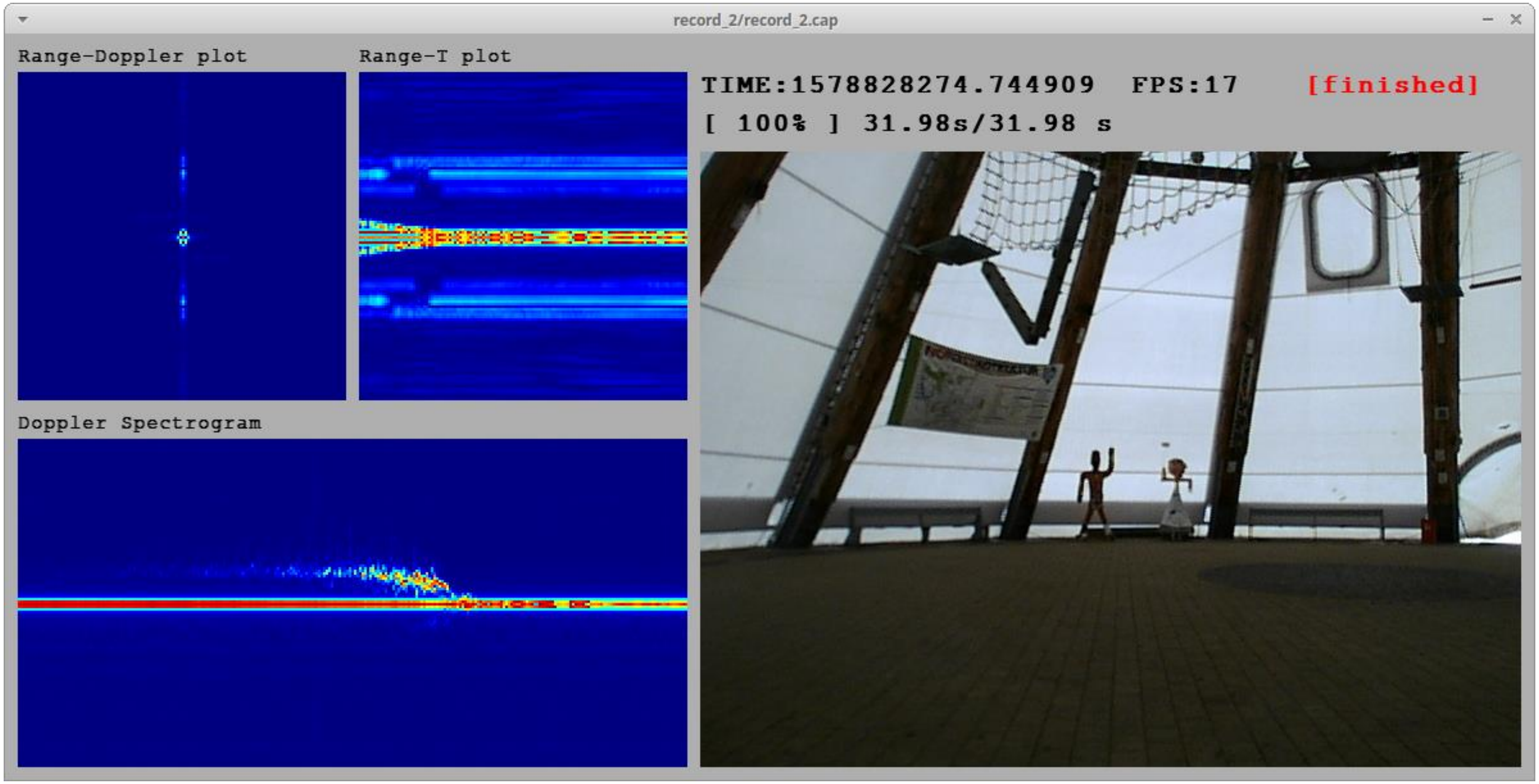


4.2 Live tracking tool

Application features:

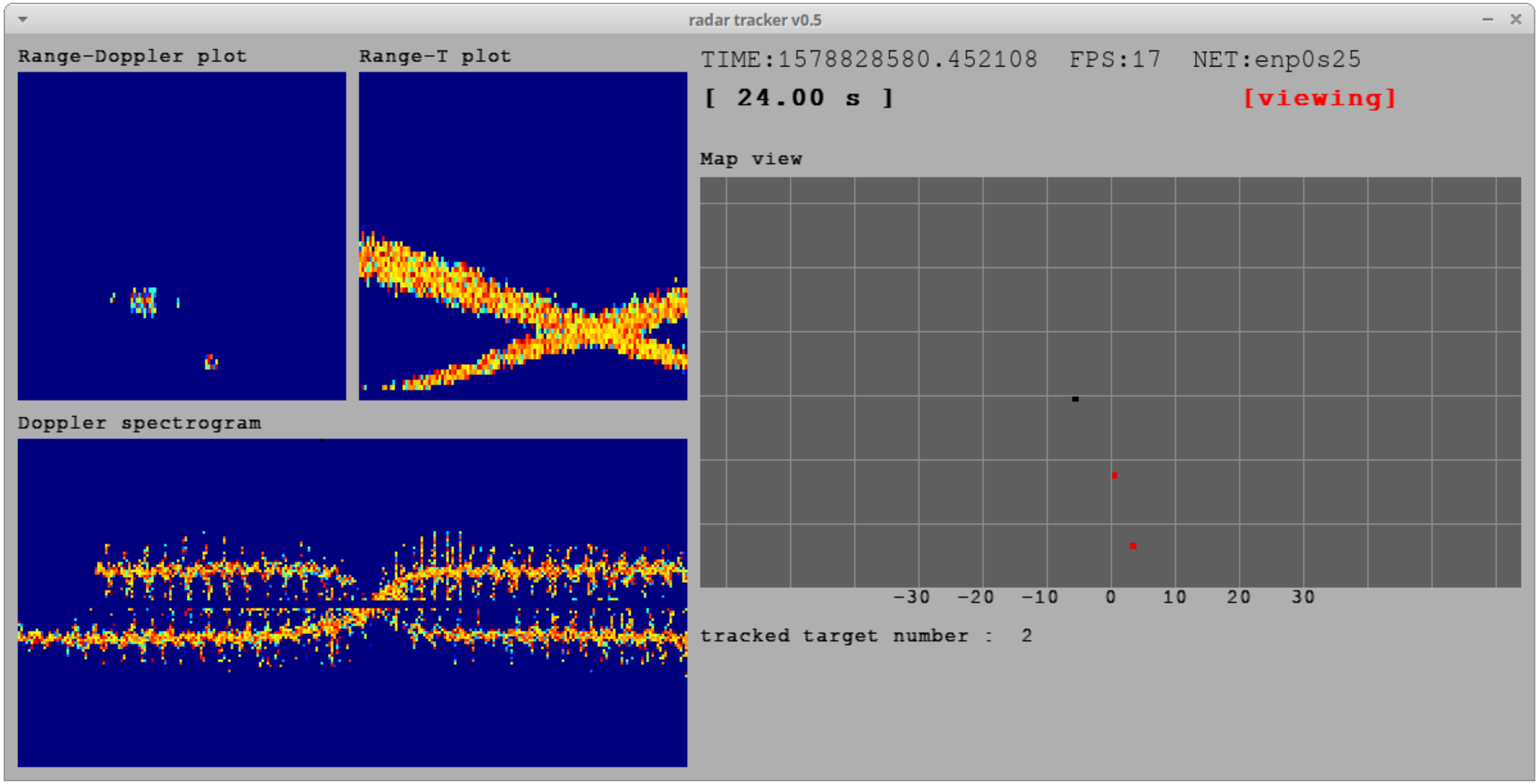
1, visualize incoming radar signal

2, single tracking mode, show detailed features of a single target

3, multi-target tracking mode, show the map view of the tracked targets

4, operate by key press

4.2 Live tracking tool



Section 5: Summary

5.1 Conclusion

Detection: 2D Maxima and CA-CFAR

Tracking: Multi-target Kalman tracker

Recognition: two pass sampling technique

Classification: simple classification by features is possible

5.2 Future research

Angle separation

Loop optimization, parallelization

Walking model optimization, other features

Port algorithms into radar module

Classification

Thank you

Backup slides

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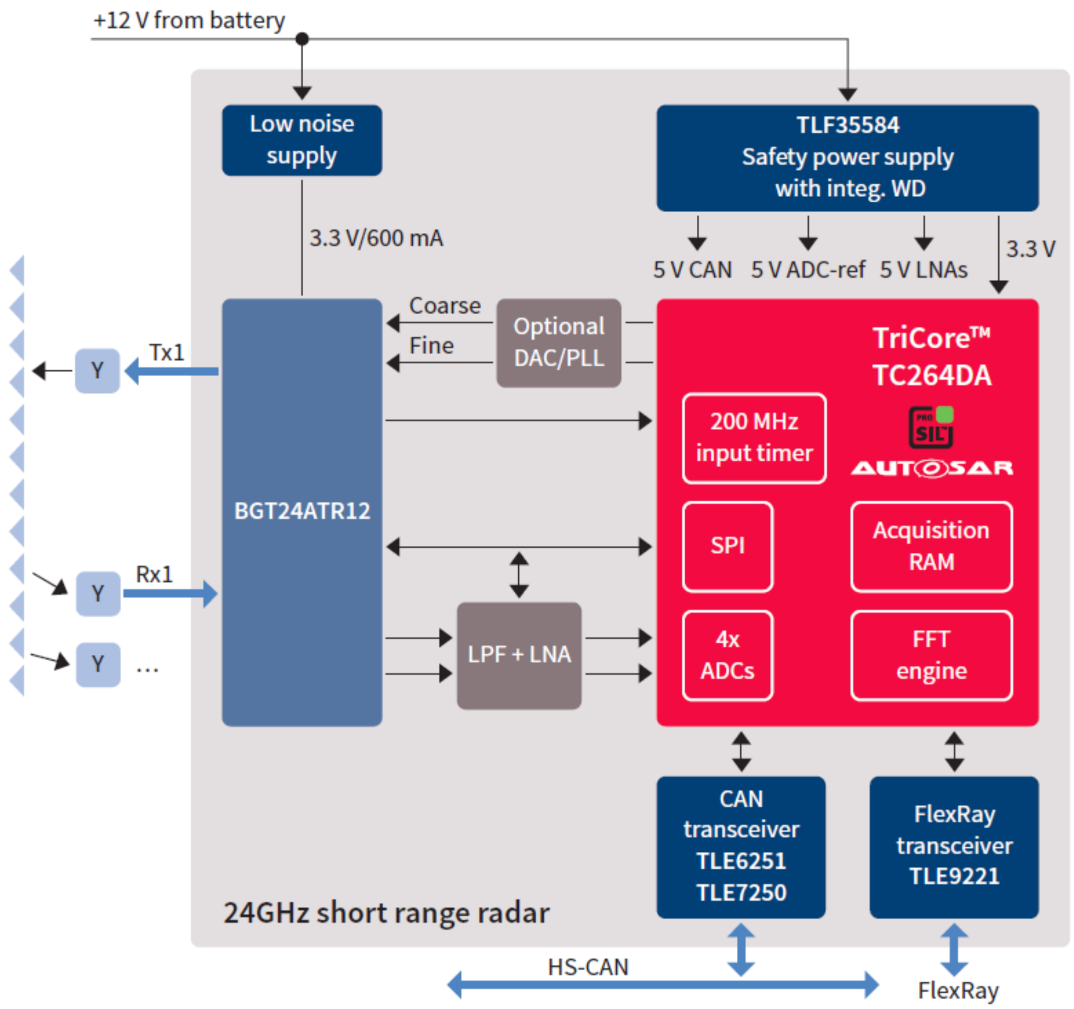
Infinion 24 GHz automotive radar kit (block diagram)



1.4 Literature research

- Clutter filtering
- Clustering algorithms
  - K-Means Clustering, Mean-Shift, DBSCAN
- Kalman Filter
- Classification
  - SVM, HMM

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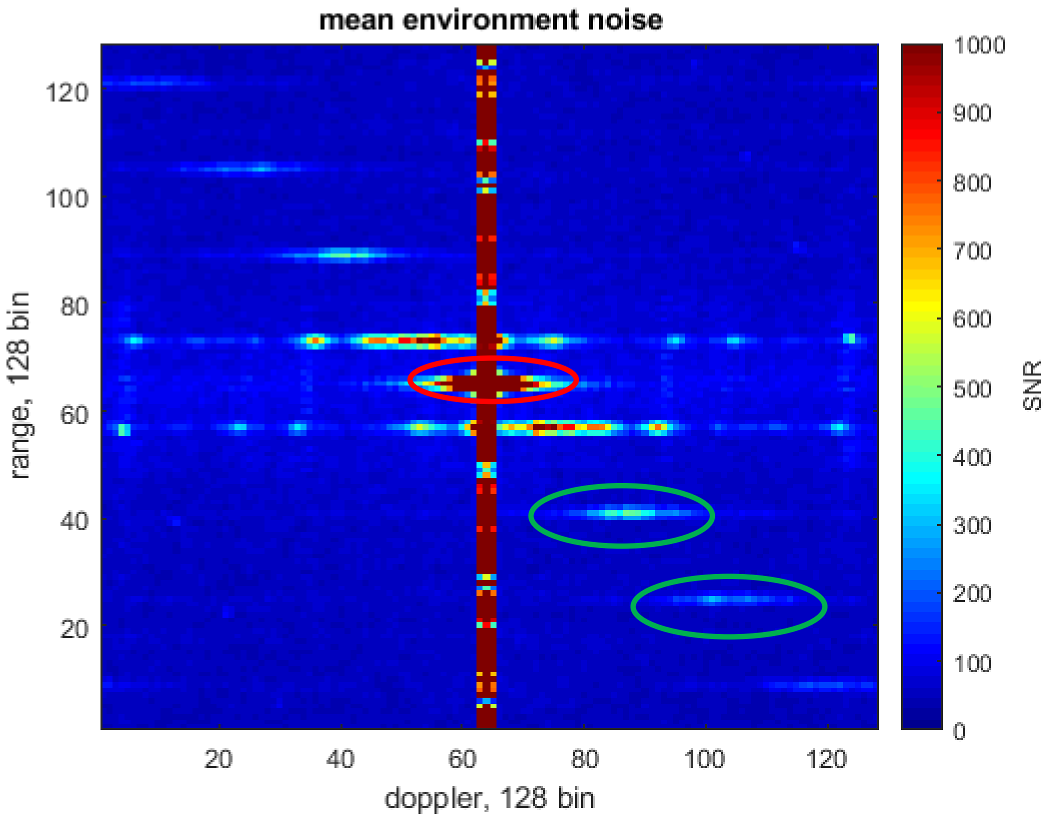
2.1.2 **Clutter removal**

stationary clutter

correlated clutter



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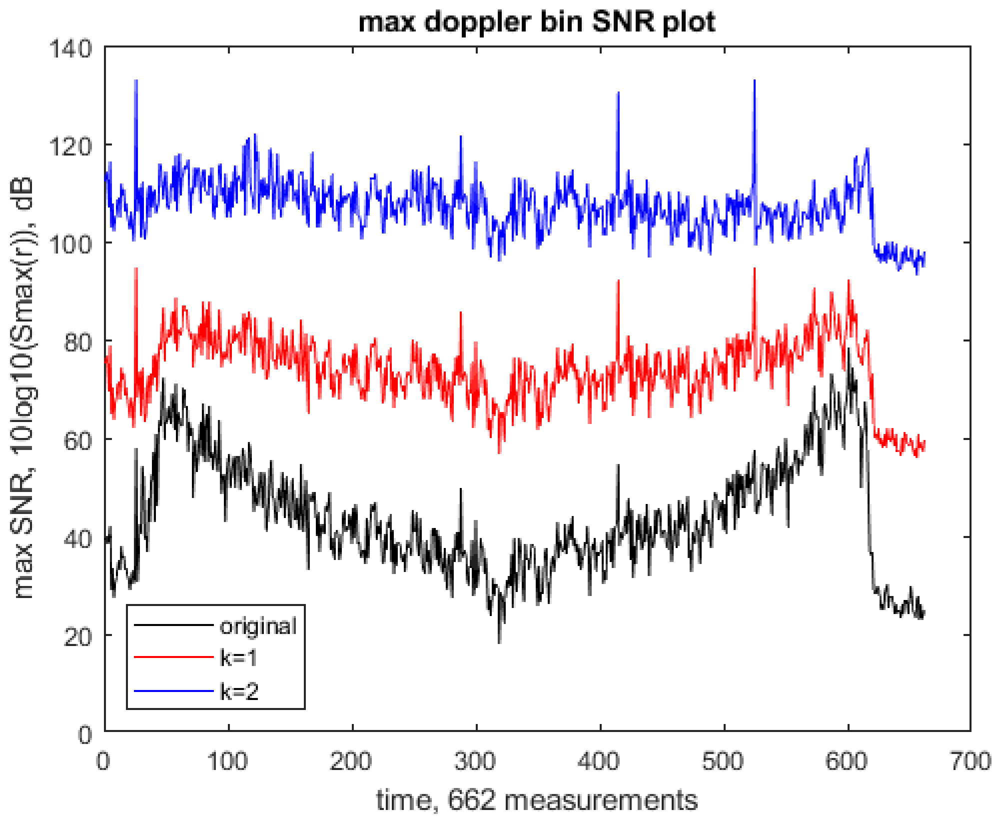
2.1.3 **Weak signal enhancement**

the time gain method, $b_{r,d} = a_{r,d} \cdot r^k, k = 1,2, \dots, n$



2.1 Signal preprocessing

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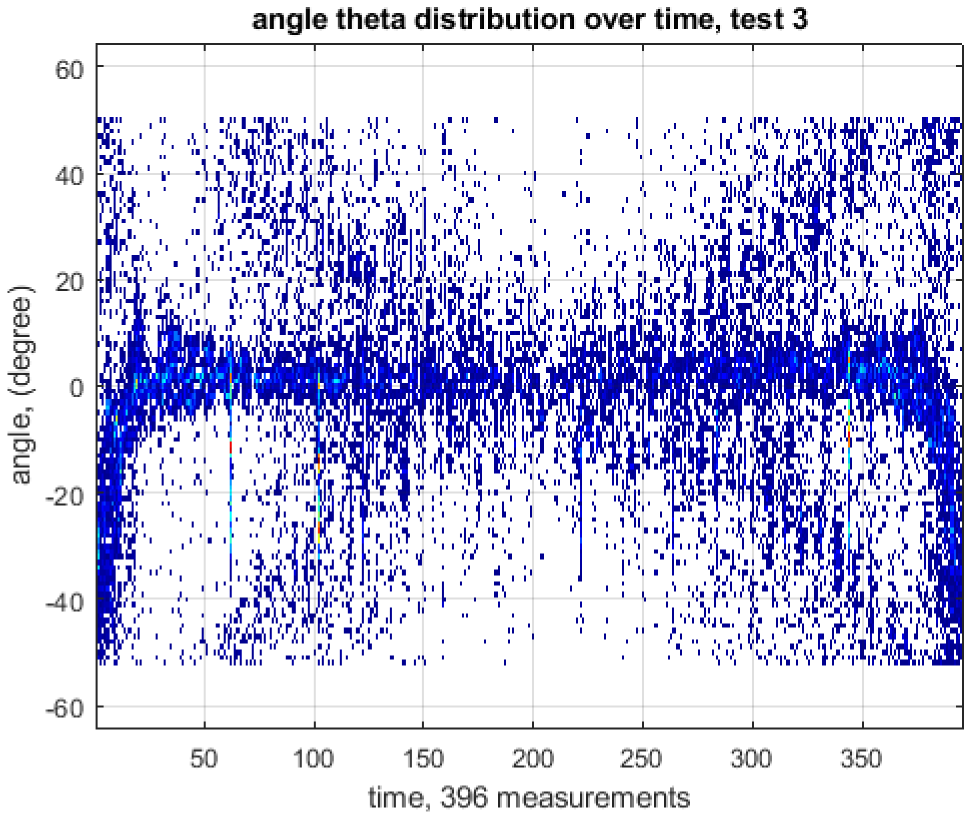
2.1.4 **Signal detection**

angle pre-separation (3 person)



2.2 Target tracking

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2.2.1 Kalman filter

prediction

$$\bar{X}_t = A \cdot X_{t-1}$$

$$\bar{P}_t = A \cdot P_{t-1} \cdot A^T + E_x$$

$$\begin{bmatrix} x \\ y \\ v_x \\ v_y \end{bmatrix}_t = \begin{bmatrix} 1 & 0 & T & 0 \\ 0 & 1 & 0 & T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ v_x \\ v_y \end{bmatrix}_{t-t}$$

update

$$K_t = \bar{P}_t \cdot H^T \cdot (H \cdot \bar{P}_t \cdot H^T + E_z)^{-1}$$

$$X_t = \bar{X}_t + K_t \cdot (z_t - H \cdot \bar{X}_t)$$

$$P_t = (I - K_t \cdot H) \cdot \bar{P}_t$$

2.2 Target tracking

2.2.1 Kalman filter

$$A = \begin{bmatrix} 1 & 0 & T & 0 \\ 0 & 1 & 0 & T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}, \quad T \approx 59.6ms$$

$$E_x = \begin{bmatrix} \frac{T^4}{4} & 0 & \frac{T^3}{2} & 0 \\ 0 & \frac{T^4}{4} & 0 & \frac{T^3}{2} \\ \frac{T^3}{2} & 0 & T^2 & 0 \\ 0 & \frac{T^3}{2} & 0 & T^2 \end{bmatrix} \qquad E_z = \begin{bmatrix} z_x & 0 \\ 0 & z_y \end{bmatrix}, \quad z_x = z_y \approx \text{1e−2}$$

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2.2.3 Multi-target tracking

hungarian algorithm

7	8	89	43	84
13	3	69	83	27
5	1	22	6	34
21	4	45	24	2
6	33	5	58	29

Objective: minimize cost

Min cost = 7+3+5+6+2=23

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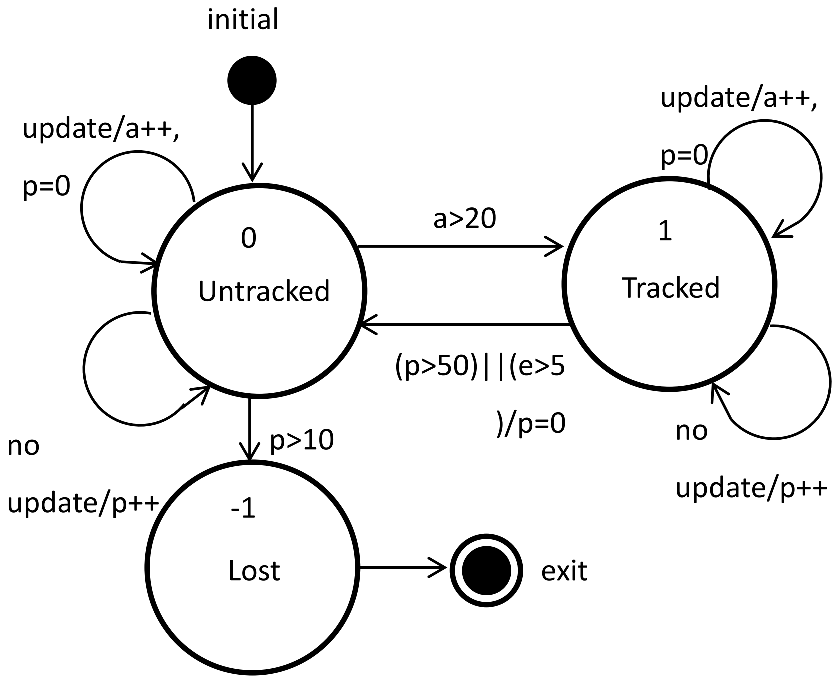
2.2.3 Multi-target tracking

track state transition



a: the number of valid target inputs of a track

p: the number of continuous updates without valid target input

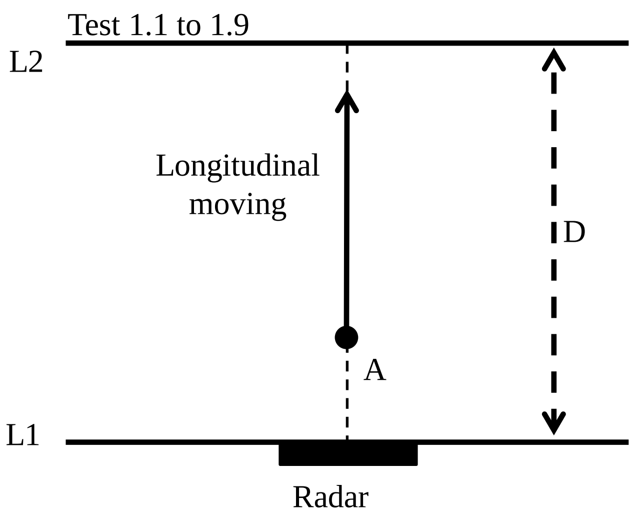
e: the mean error between the target input and estimation

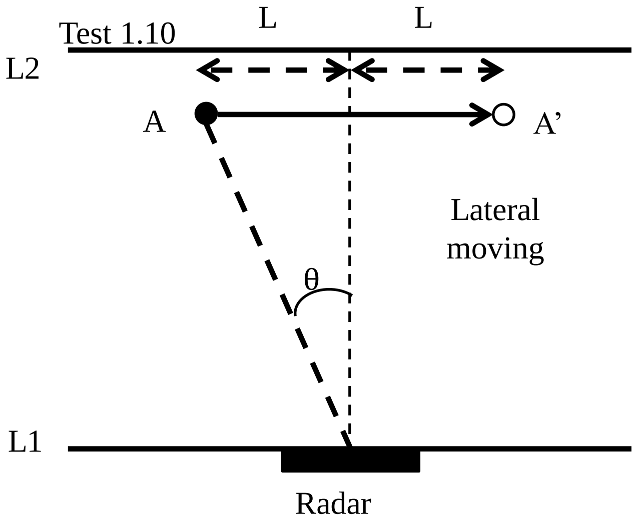
3.1 Test cases 1

Test 1.1 – 1.10

Scenario: One people walking (longitudinal and lateral)

Objective: Test basic measurement capabilities



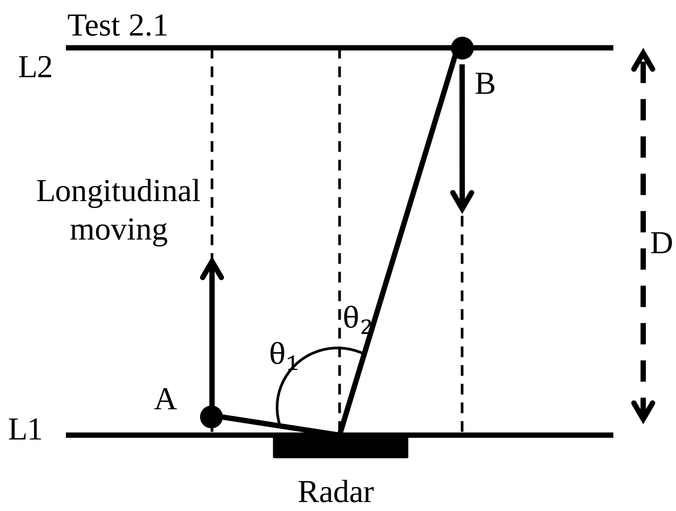


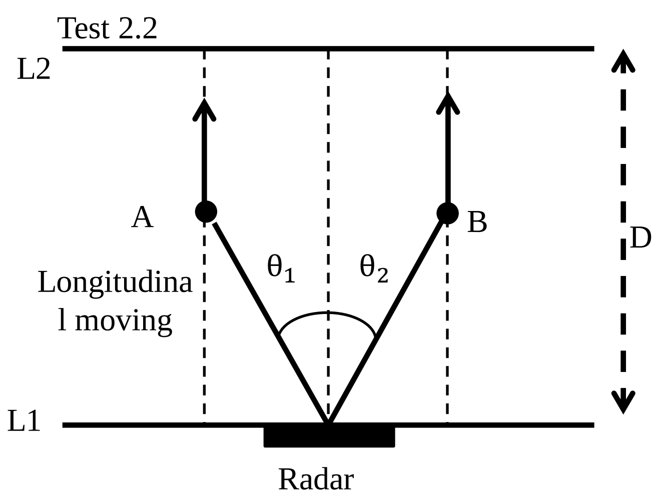
3.2 Test cases 2

Test 2.1 – 2.2

Scenario: two people walking (longitudinal and lateral)

Objective: test the two target measurement capabilities





3.2 Test cases 2 Test 2.1 – 2.2 tracking result

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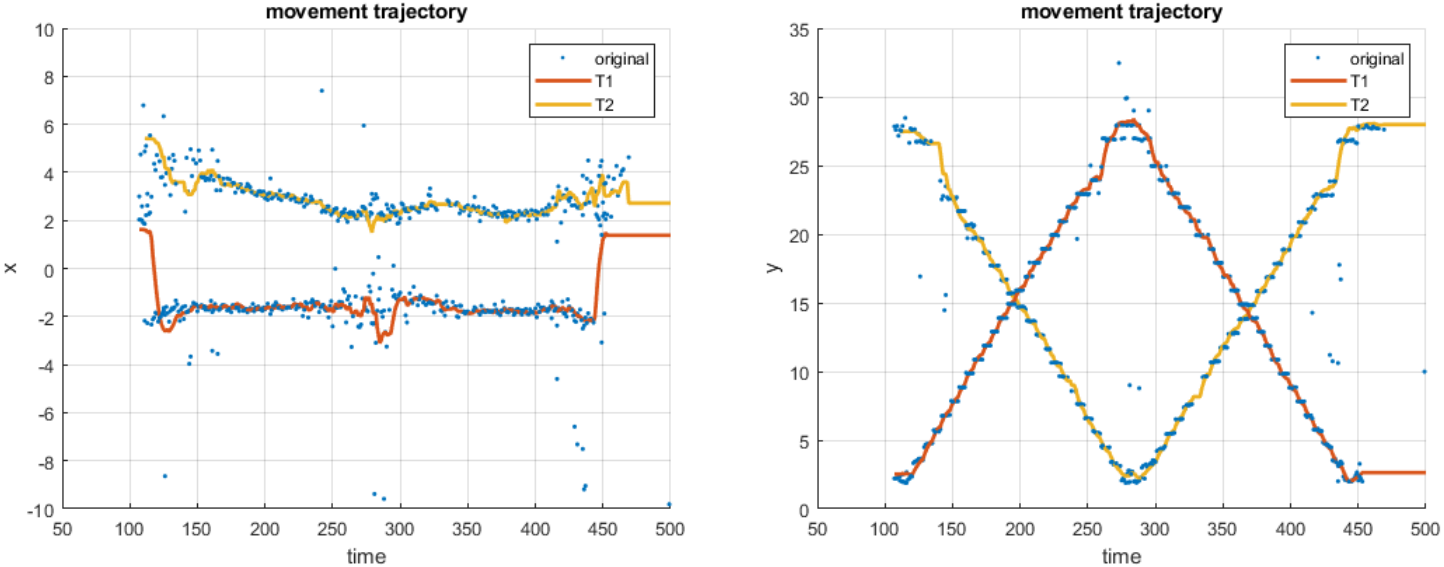
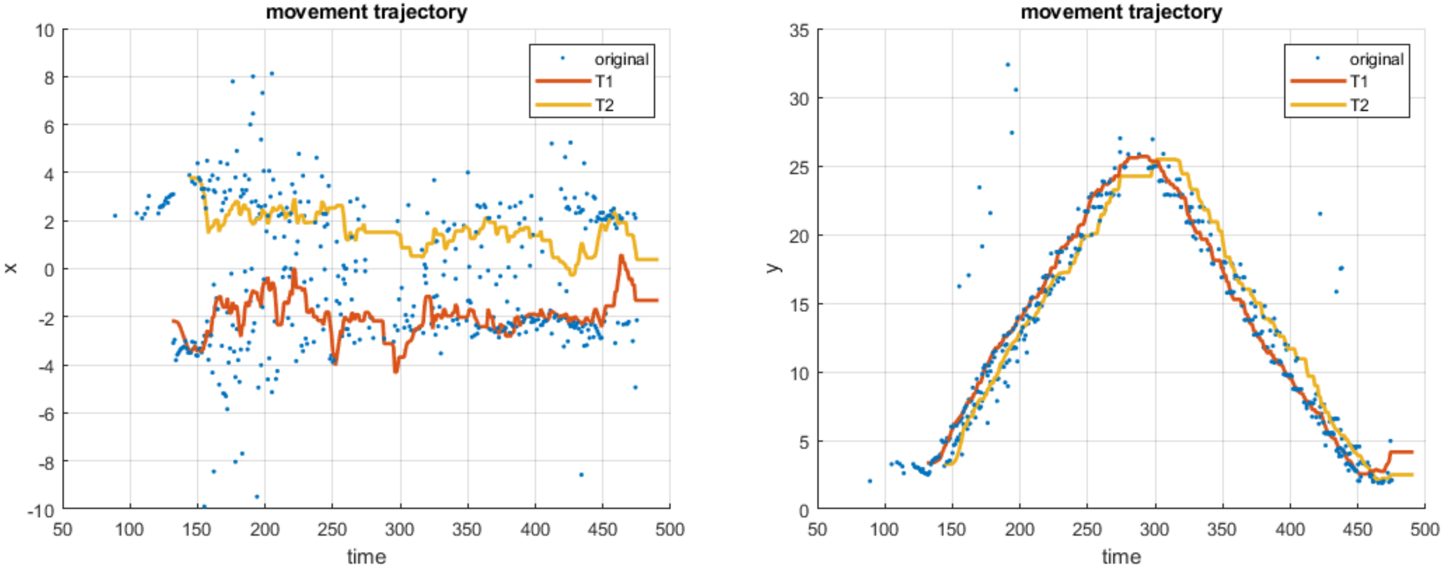
Test 2.1



Test 2.2

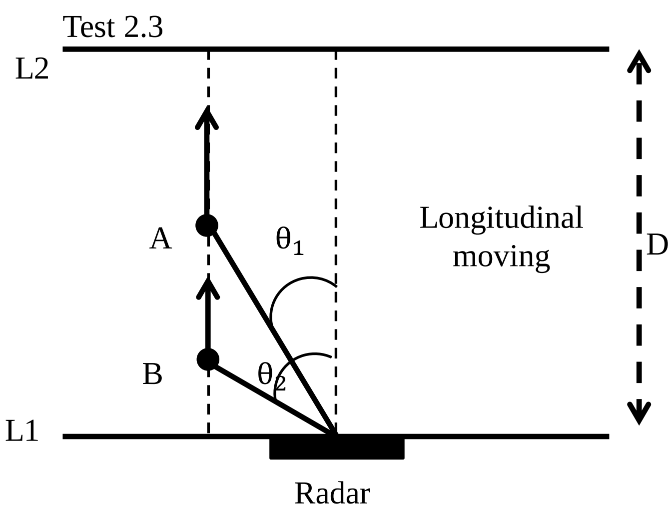


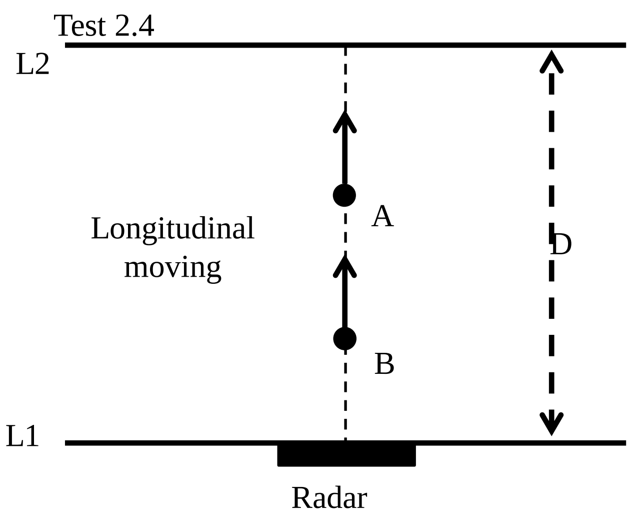
3.2 Test cases 2

Test 2.3 – 2.4

Scenario: two people walking (longitudinal and lateral)

Objective: test the two target measurement capabilities





3.2 Test cases 2 Test 2.3 – 2.4 tracking result

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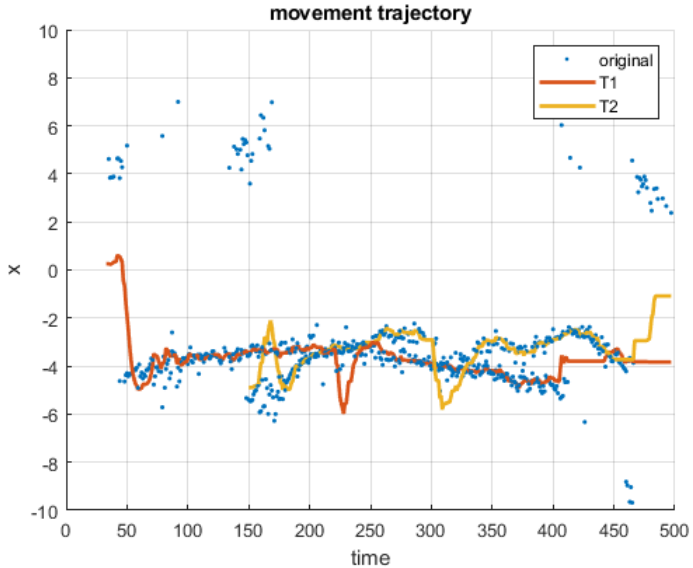
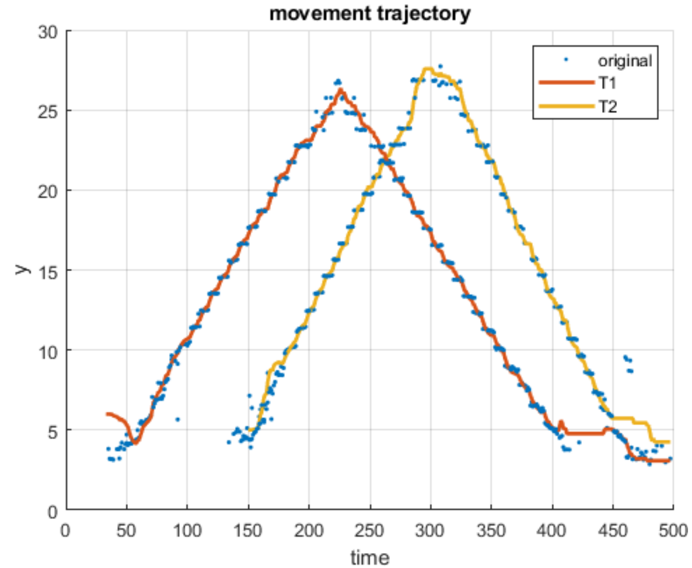
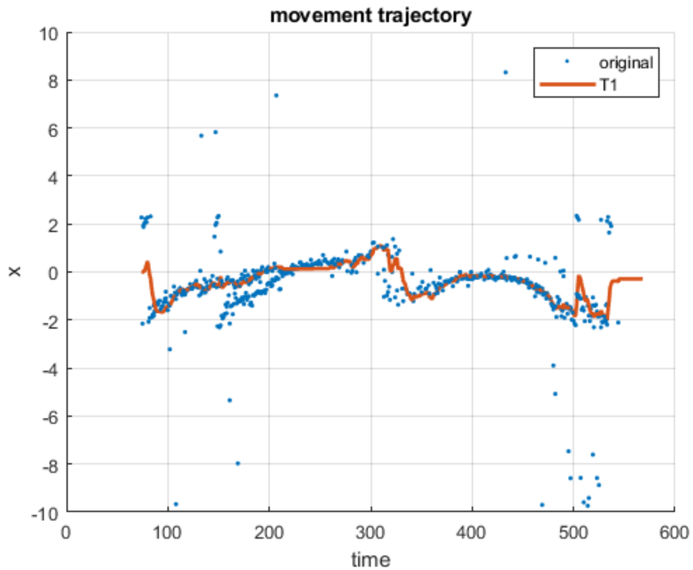
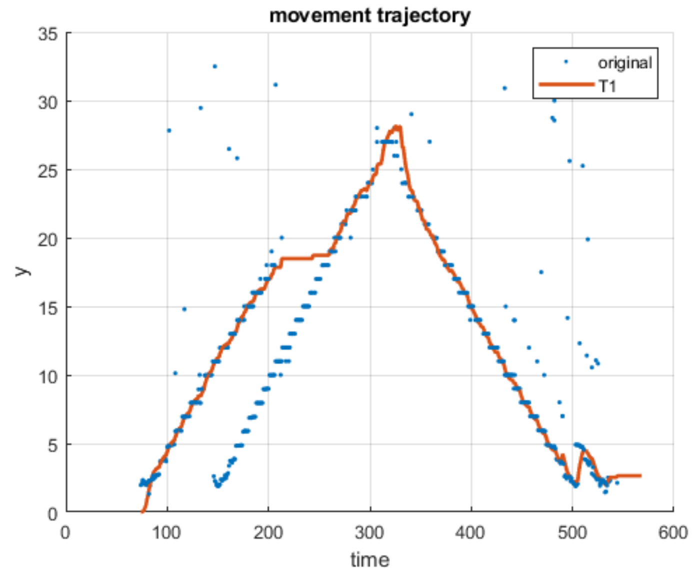
Test 2.3





Test 2.4





3.2 Test cases 3

Test 3

Scenario: three people walking (longitudinal).

Objective: test the three target measurement capabilities