HIGH RESOLUTION AND IMAGING RADAR

1. Prerequisites

- Basic knowledge of radar principles.
- Good background in Mathematics and Physics.
- Basic knowledge of MATLAB programming.

2. Course format and dates

The course is divided in two sections. A first section will consist of five days of intensive lectures over a week period. The second part of the course will have duration of three weeks with five hours per week. This part of the course will be organized by using videoconference tools, such as Skype or others.

The student assessment is organized into two tests:

1) Solutions of assigned drill problems
2) 3-hour examination

During the intensive five-day course, practical sessions, also with the use of MATLAB, will be interwoven with classic lectures. Practical sessions are intended to strengthen the understanding of the theory and are based on running routines that implement high resolution and imaging radar algorithms. The student will familiarise themselves with the problems and will learn how to set system parameters to achieve desired performances.

Follow up sessions will aim to

1. provide support for solving the assigned drill problems
2. provide further clarifications about course topics
3. give specific seminars on topics related to assigned drill problems

3. Staff

Dr. Marco Martorella – University of Pisa – m.martorella@iet.unipi.it

Prof. Fabrizio Berizzi – University of Pisa – f.berizzi@iet.unipi.it

4. Course description

The course is organized in three parts, which mainly cover aspects related to High Resolution Radar (HRR), Synthetic Aperture Radar (SAR) and Inverse Synthetic Aperture Radar (ISAR).

4.1. HRR

It is well known that radars used for surveillance have poor spatial resolutions. In these systems, spatial resolution cells are usually much greater than the target size. Detections are generally presented as a single spot in the radar display and the target visible characteristics are those of a point scatterer.

When target details are needed, a fine spatial resolution is required. The first step is to improve range resolution. This can be achieved by using coded waveforms and pulse compression techniques, which make use of matched filtering and cross-correlation algorithms. In this Masters course, the following topics related to HRR will be covered:

- pulse compression principles,
- introduction to wide instantaneous bandwidth waveforms,
- range profile formation techniques.
- FMCW radar

4.2. SAR

Radar images are obtained by pushing the resolution along two coordinates, namely the range and cross-range (or azimuth). Whilst the former can be achieved by using pulse compression, the latter must be obtained by means of very large antennas (or antenna arrays). SAR (Synthetic Aperture Radar) techniques overcome the problem of building real antenna or antenna arrays, which in some cases would prove impossible. By moving the antenna from pulse to pulse to different positions, a virtual array can be formed. By coherently processing the received signal, a large antenna array with narrow beam-width can be synthesized.

In this Masters course, the following topics will be addressed:

- SAR geometry. The main SAR geometries and the relevant parameters will be introduced.
- Side-looking (SL) SAR imaging: the main techniques for image reconstruction will be described.
- FMCW SAR
- SAR system design techniques. Introduction to methods for designing SAR image systems and application to some simple cases.
- Spotlight SAR. Overview of the main Spot-light SAR imaging techniques.
- Survey of past and current space-borne SARs.
- Implementation of range profile SAR image reconstruction algorithms. A practical session will follow after each main section. A practical session will consist of running MATLAB codes (provided by the presenter) that will implement simple range profile and SAR image reconstruction algorithms. The practical session will help the student to understand concepts and techniques.

4.3. ISAR

ISAR has become a powerful tool for obtaining radar images of targets. Modern high resolution tracking radars implicitly offer the system requirements needed for implementing ISAR imaging. ISAR images are obtained by means of a signal processing that can be enabled both on and off-line. Non-Cooperative Target Recognition (NCTR) systems are often based on the use of ISAR images because they provide a 2D e.m. map of the target reflectivity. Therefore, classification features that contain spatial information can be extracted and used to increase the performance of classifiers.

In this Masters course, the following topics will be covered

- Introduction to ISAR. ISAR is introduced by defining the radar-target geometry and by considering simple radar concepts.
- ISAR processing. The derivation of the ISAR processor is obtained by defining the signal model and by interpreting it in the Fourier domain. Basic and advanced techniques are presented in order to provide an understanding of the current methods used for implementing ISAR and improving its performance.
- ISAR image autofocus. The problem of ISAR image autofocus is analysed in detail and several solutions are presented.
- Advanced Techniques. The time window selection and cross-range scaling problems are addressed in order to obtain radar images of non-cooperative targets that can be directly used for classification and recognition purposes
- Implementation of ISAR algorithm. A practical session will follow after each main section. The practical session will consist of running MATLAB codes (provided by the presenter) that will implement simple ISAR algorithms. The practical session will help the student to understand concepts and techniques.

5. Learning outcomes

Having successfully completed this course, students should:

- Understand the concept behind high resolution radar, SAR and ISAR
- understand the techniques that are currently used in high resolution radar, SAR and ISAR and be able to choose which ones are the most suitable for a given scenario,
- understand the significance of using SAR/ISAR images in a number of applications,
- be able to implement simple SAR/ISAR algorithms,
- understand the main differences between radar imaging of static scenes and non-cooperative moving targets,
- be able to predict radar imaging performance in some scenarios.

6. Textbook

Detailed presentation slides will be made available to students before the course starts.

V. C. Chen, M. Martorella, “Inverse Synthetic, “Inverse Synthetic Aperture Radar Imaging: Principles, Algorithms and Applications”, IET/Scitech Publishing, 2014

7. Description of topics (L=lecture, P=Practical session)

L1. Introduction to radar systems (definition and nomenclature) (1h)

L2. High Range Resolution (HRR) radar (3h)

2.1. Pulse compression principles

2.2 High Range resolution techniques

2.2.1 Instantaneous bandwidth waveforms

- Chirp pulses
- Binary phase coded signals

2.2.2 High range resolution reconstruction

- Chirp pulse compression (Matched filtering and de-chirping)
- Binary digital pulse compression

2.3 Waveform design and range profiling examples

2.4 FMCW radar

P1. Range Compression (1h)

P1.1. Generation of chirp signals and calculation of the Matched Filter (MF) output

P1.2. Generation of a Barker code phase modulated signal and calculation of the MF output

P1.3 Stepped frequency signal generation and compression

P1.4 FMCW signal generation and processing

L3. Real Aperture Radar imaging (2h)

3.1. Introduction

3.2. Circular scan Real Aperture Radar (CS-RAR)

3.3. Side looking Real Aperture Radar (SL-RAR)

3.3.1 System geometry

3.3.2 Spatial resolution

3.3.3 Image formation

L4. Side-looking Synthetic Aperture Radar (SAR) (9h)

4.1. Principles

4.2. Coherent integration technique

4.3. Strip-map SAR image formation

4.4. Range Doppler Technique

- 4.5 Chirp scaling technique (principles)
- 4.6. System design
  - 4.6.1. Focus depth
  - 4.6.2. PRF constraints
  - 4.6.3. Range Migration
- 4.7. System design examples
- 4.8. Multi-look mode
- 4.9. Scan-SAR mode
- 4.10 FMCW SAR

P2. SAR Signal Generation (1h)

- P2.1. Scenario generation
- P2.3. Generation of platform motion
- P2.4. Generation of the received signal

P3. SAR image reconstruction (1h)

- P3.1. Platform motion compensation
- P3.2. Strip-map image reconstruction
- P3.3 FMCW SAR image formation

L5. Spot-light SAR (principles) (4h)

- 5.1. System geometry
- 5.2 Received signal model (time and spectral behaviour)
- 5.3 Overview of image reconstruction techniques

L6. Overview of current and past SAR systems (1h)

L7. ISAR Geometry and Signal Modelling (1h)

- 7.1. System geometry
- 7.2. Target modelling
- 7.3. Received signal model
- 7.4. Interpretation of the received signal model

P4. ISAR Signal Generation (1h)

- P2.1. Generation of a point-like target

P2.2. Generation of target's motions

P2.3. Generation of Radar-target kinematics

P2.4. Generation of the received Signal

L8. ISAR Image Formation (3h)

8.1. RF Front-End and Signal demodulation

8.2. Radial motion compensation (Autofocusing)

8.3. Image formation

8.4. Interpretation of ISAR images

8.5. Point spread function

8.6. Image resolution

8.7 CLEAN ISAR image formation

L9. ISAR Image Autofocus (1h)

9.1. Parametric and non-parametric techniques

9.2. Hot Spot Processing (Prominent Point Processing)

9.3. Phase Gradient Autofocus (PGA)

9.4. Image Contrast Based Autofocus (ICBA)

9.5. Image Entropy Based Autofocus (IEBA)

P5. ISAR image reconstruction (2h)

P5.1. Autofocusing

P5.2. Range-Doppler image formation

P5.3. Time-Frequency-range image formation

P5.4. CLEAN ISAR image formation

L10. Time-Window Selection and cross-range scaling (2h)

10.1. Problem statement

10.2. Max Contrast Algorithm

10.3. Ad-hoc techniques for ISAR imaging of ships

10.4 Chirp estimation method

P6. ISAR time windowing and cross-range scaling (2h)

P6.1. ISAR movie generation

P6.2. Most focused image selection

P6.3. Chirp estimation method

L11. ISAR applications (1h)

12.1. Ground-based ISAR

12.2. Airborne ISAR

12.3. Space-borne ISAR

12.4 ISAR from SAR

12.5 Closing remarks

8. **Lecture programme**

Time	**Mon 18/7**	**Tue 19/7**	**Wen 20/7**	**Thu 21/7**	**Fri 22/7**
08h30	L1.	L4.2,L4.3	P2	P4	L10.1,L10.2
09h30	L2.1	L4.4	P3	L8.1,L8.2	L10.3,L10.4
10h30	Coffee break	Coffee break	Coffee break	Coffee break	Coffee break
11h30	L2.2	L4.5	L5.1,L5.2	L8.3,L8.4	P6.1,P6.2
12h00	L2.3	L4.5	L5.3	L8.5,L8.6	P6.3
13h00	Lunch	Lunch	Lunch	Lunch	Lunch
14h00	P1	L4.6	L5.3	L8.7	L11.1,L11.2
15h00	L3.1,L3.2	L4.6	L5.3	L9	L11.3,L11.4
16h00	L3.3	L4.7	L6	P5.1,P5.2	P7
17h00	Tea	Tea	Tea	Tea	Tea
17h30	L4.1	L4.8,L4.9	L7	P5.3,P5.4	L12
18h30	Close	Close	Close	Close	Close

Item	**Number**	**Hrs/per**	**Hours**
Lectures	40	1	40
Assimilation	40	3	120
Seminar attendance	3	5	15

Drill Problems	3	5	15
Examination preparation	1	8	8
Examination	1	3	3
Total			201