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Doctoral Thesis

Multi-channel Techniques for 3D ISAR

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Declaration of Authorship

I, Federica SALVETTI, declare that this thesis titled, 'Multi-channel Techniques for 3D ISAR' and the work presented in it are my own. I confirm that:

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"A person who never made a mistake never tried anything new."

Albert Einstein

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Abstract

Doctor of Philosophy

Multi-channel Techniques for 3D ISAR

by Federica SALVETTI

This thesis deals with the challenge of forming 3D target reconstruction by using spatial multi-channel ISAR configurations. The standard output of an ISAR imaging system is a 2D projection of the true three-dimensional target reflectivity onto an image plane. The orientation of the image plane cannot be predicted a priori as it strongly depends on the radar-target geometry and on the target motion, which is typically unknown. This leads to a difficult interpretation of the ISAR images. In this scenario, this thesis aim to give possible solutions to such problems by proposing three 3D processing based on interferometry, beamforming techniques and MIMO InISAR systems. The CLEAN method for scattering centres extraction is extended to multichannel ISAR systems and a multistatic 3D target reconstruction that is based on a incoherent technique is suggested.

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Abbreviations

2D	**2 D**imensional
3D	**3 D**imensional
DSTO	**D**efence **S**cience **T**echnology **O**rganization
EM	**E**lectro**M**agnetic
FMCW	**F**requency **M**odulated **C**ontinuous **W**ave
FT	**F**ourier **T**ransform
IC	**I**mage **C**ontrast
ICBA	**I**mage **C**ontrast **B**ased **A**utofocus
IFT	**I**nverse **F**ourier **T**ransform
InISAR	**In**terferometric **I**nverse **S**ynthetic **A**perture **R**adar
ISAR	**I**nverse **S**ynthetic **A**perture **R**adar
IPP	**I**mage **P**rojection **P**lane
LoS	**L**ine **o**f **S**ight
MC-CLEAN	**M**ulti**C**hannel **CLEAN**
M-ICBA	**M**ultichannel **I**mage **C**ontrast **B**ased **A**utofocus
MIMO	**M**ultiple **I**nput **M**ultiple **O**utput
MF	**M**atched **F**ilter
PLS	**P**robabilistic **L**east **S**quare
Pol-CLEAN	**Pol**arimetric **CLEAN**
PSF	**P**oint **S**pread **F**unction
PRF	**P**ulse **R**epetition **F**requency
PRI	**P**ulse **R**epetition **I**nterval
RADAR	**RA**dio **D**etection **A**nd **R**anging
RCS	**R**adar **C**ross **S**ection

RD	**R**ange **D**oppler
RT	**R**adon **T**ransform
RX	**R**eciving
SAR	**S**ynthetic **A**perture **R**adar
SLL	**S**ide **L**obe **L**evel
SNR	**S**ignal to **N**oise **R**atio
TX	**T**ransmitting

Symbols

A

A^i received signal amplitude of the i^{th} spatial channel

a_r focusing parameter of the ICBA algorithm corresponding to the accellera

B

B signal bandwidth

C

c speed of light

$\boldsymbol{C_m}$ model coordinates

$\boldsymbol{C_{rt}}$ coordinates of the model rotated along the trajectory

D

d_H horizontal baseline length

d_V vertical baseline length

D_{cr} size of the antenna along a given cross-range direction

E

$E_{g_{i^*}}$ energy of a time-delay section in the i^{th} spatial channel

F

f_0 carrier frequency

f_d Doppler frequency

F percentage of initial energy of the ISAR image

G

H

h_H scatterer's height along the horizontal baseline

h_V scatterer's height along the vertical baseline

	I
$\boldsymbol{i_{LoS}}$	LoS unit vector
$I(\tau, \nu)$	ISAR image in the range-Doppler domain
	J
$J(\boldsymbol{\alpha}$	cost function of the soft assignment
	K
k_0	wavenumber
	L
	M
$\boldsymbol{M_{\xi x}}$	rotation matrix
$mmd_k(n)$	mean matching distance
	N
	O
O	centre of the reference system
	P
$\boldsymbol{P_j}$	position at time $t = 0$ for a generic scatterer in the local reference system T_j
$\mathbf{p}_{Tm}$	m^{th} tx coordinates in the local system of reference
$\mathbf{p}_{Rn}$	n^{th} rx coordinates in the local system of reference
	Q
Q	number of sensor in the multistatic network
	R
R_0	radar-target distance
$\boldsymbol{R_\mu}$	yaw matrix
$\boldsymbol{R_\nu}$	pitch matrix
$\boldsymbol{R_\xi}$	roll matrix
	S
$S_R(f,t)$	spectrum of the time-varying spatial multichannel received signal
	T
T_i	transmitted pulse duration
T_ξ	reference system embedded in the radar
T_i	transmitted pulse duration

T_{obs}	observation time
T_R	pulse repetition interval
T_x	time-varying reference system embedded in the target
T_y	reference system T_x at $t = 0$
	U
	V
v_r	radial velocity
	W
$w(\tau, \nu)$	Point Spread Function
$W(f, t)$	domain where the 2D FT of the reflectivity function is defined
	X
	Y
y_{ij}	i^{th} y-coordinate in the local reference system T_j
	Z

Greek Symbols

	$\boldsymbol{\alpha}$
α	azimuth angle
α_{cr}	angular resolution of a rectangular antenna
$\boldsymbol{\alpha}$	soft assignment matrix
$\alpha_{i,k}$	assignment probability between the k^{th} and the i^{th} scatterer
	$\boldsymbol{\beta}$
	$\boldsymbol{\gamma}$
γ	empiric parameter to adjust the threshold Λ
	$\boldsymbol{\delta}$
δ_{cr}	cross-range resolution
δ_r	range resolution
δ_τ	pulse duration at the output of the MF
Δ_ν	Doppler resolution
Δ_τ	time delay resolution
Δ_{y_1}	spatial resolution along y_1

Δ_{y_2}	spatial resolution along y_2
	$\boldsymbol{\epsilon}$
$\varepsilon_{i,k}$	euclidean distance between k^{th} and the i^{th} scatterer
ϵ_h	height error
ϵ_ϕ	ϕ error
ϵ_Ω	effective rotation angle error
	$\boldsymbol{\zeta}$
ζ	compression factor
	$\boldsymbol{\theta}$
θ	elevation angle
	$\boldsymbol{\lambda}$
λ	wavelength
Λ	threshold to identify unreliable assignments
	$\boldsymbol{\mu}$
μ	chirp rate
	$\boldsymbol{\nu}$
ν	Doppler frequency
	$\boldsymbol{\rho}$
ρ	reflectivity function
	$\boldsymbol{\sigma}$
σ_{ϵ_h}	standard deviation of ϵ_h
	$\boldsymbol{\tau}$
τ	time delay
	$\boldsymbol{\phi}$
ϕ	rotation angle between T_ξ and T_x
	$\boldsymbol{\varphi}$
φ	angle between the scatterers trace and the abscissa axis
	$\boldsymbol{\chi}$
	$\boldsymbol{\psi}$
$\Psi(a, b)$	function to be minimised for the estimation of Ω_{eff} and ϕ
	$\boldsymbol{\omega}$

$\boldsymbol{\Omega_{eff}}$	effective rotation vector
$\boldsymbol{\Omega_{T}}$	total angular rotation vector

Math Operators

$A\{\}$	expectation
$E\{\}$	expectation
$\delta_{i,j}$	Dirac delta function
T	transpose operator