AN ENHANCED MINIMUM VARIANCE DISTORTIONLESS RESPONSE BEAMFORMER TECHNIQUES TO REDUCE INTERFERENCE IN ARRAY ANTENNA SYSTEM

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I hereby declare that the work in this thesis is based on my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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DEDICATION

Allah, there is no pleasure in the night without your praise, there is no pleasure in the day without your obedience, there is no pleasure in the moments without your mention, there is no pleasure in the other world without your forgiveness, and there is no pleasure in heaven without your sight
Allah, Almighty

To whom who sent the message and led the Secretariat and advised the nation,
To the Prophet of mercy and the light of the Worlds,
Muhammad, peace be upon him

To whom I carry his name with pride. To Whom, I missed so long ago
To whom my heart trembles remember. To whom who let me to *Allah*.
My Dear father

To my angel in life, to the meaning of love, compassion, and dedication, to the smile of my life and the secret of existence
To one whose prayers are the secret of my success and whose affection is the cure to my wounds to the most and the dearest loved ones
My Beloved Mother

To those who are closer to my soul than me, to those who share my mother's passion with me, to those from whom I derive persistence
My Brothers and Sisters

To the one I grow with her and I depend on her. To the burning candle that illuminates the darkness of my life. To the one form her, I gained strength and boundless love
To the one with whom I knew the true meaning of life
My Wife and our angels: Mariam & Mairan

I dedicate this work

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a	Scalar
a	Vector
$\mathbf{A}$	Matrix
$\lvert\cdot\rvert$	Absolute value
$\lvert\cdot\rvert^2$	Absolute square value
$[\cdot]^{\dagger}$	Complex conjugate (Hermitian transpose) of a vector or matrix
$[\cdot]^{*}$	Complex conjugate of a vector or matrix
$[\cdot]^{-1}$	Matrix inversion
$[\cdot]^{T}$	Transpose of a vector or matrix
$E\{\cdot\}$	Expectation operator (Statistical averaging operator)
$e^{[.]}$	Exponential function
$\mathbb{R}$	Real numbers
$\mathbb{C}$	Complex numbers
$\Re\{\cdot\}$	Real part of complex number
$\Im\{\cdot\}$	Imaginary part of complex number
δ	Imaginary unit $\sqrt{-1}$
$\square^{m\times n}$	Complex $m \times n$ matrices
$\forall$	For all
$a_i^d(t)$	Acceleration of the individual i at t^{th} generation in d^{th} dimension
M_{aj}	Active gravitational mass of the j^{th} agents
χ	Array excitation weight vector coefficients
x_s	Array incident of the s^{th} desired signal
x_u	Array incident of the u^{th} interference signal
σ_y	Array output power
$y(k)$	Array output signal
$r_m(k)$	Array received signal at the mth sensor of the k^{th} snapshots
$\tilde{a}$	Array steering vector
θ, ϕ	Beam scanning range [Azimuth, Elevation]
$\beta(\theta, \phi)$	Beamformer response (Beampattern) as a function of incident angle
P_{gbest}	Best solution found all the PSO algorithm at time step t

P_{pbest}	Best solution found by particle i until time step t
$f_{best}(t)$	Best solutions of the objective function at the t^{th} iteration
X_{NM}	Candidate solution vector of n^{th} agents at m^{th} dimension
ρ	Capon DOA estimator
fc	Carrier frequency [Hz]
λ	Carrier wavelength [m]
c_1, c_2	Cognitive and social terms of PSO algorithm
$\mathbf{\Gamma}$	Covariance matrix
z_d	Cross correlation vector
θ_s, ϕ_s	Desired angle direction [°]
diag{·}	Diagonal matrix
d	Dimension of the search space
$\hat{\mathbf{\Gamma}}_{\text{SNOI}}$	Estimate of SNOI correlation matrix (Interference-plus-noise covariance matrix)
$\hat{\mathbf{\Gamma}}_{\text{SOI}}$	Estimate of SOI correlation matrix
$R_{j,i}$	Euclidean distance between the two point masses in the search space
ff	Fitness function
q	Free-space wavenumber
α	Gradient constant
G	Gravitational constant
G_0	Gravitational constant initial value
θ_z	Incident azimuth angle of the z^{th} source
ϕ_z	Incident elevation angle of the z^{th} source
M_{ii}	Inertia mass of the i^{th} agents
w	Inertia term of PSO algorithm
Δ	Interelement distance of an antenna array
J	Lagrange function
γ	Lagrange multiplier
Λ_{m}	$M \times M$ identity matrix
t_{max}	Maximum iteration (Termination condition)
$\text{SINR}\|_{\max}$	Maximum Signal to Interference plus Noise Ratio
Max-[·]	Maximum value

Min-[·]	Minimum value
σ_η	Noise power
$\vec{\Sigma}$	Noise variance
θ_u, ϕ_u	Null angle direction [°]
M	Number of elements (sensors) in the array
Z	Number of signals (sources)
K	Number of snapshots (Time stamps/Snapshots)
M_{pi}	Passive gravitational mass of the i^{th} agents
N	Population size
P	Position vector of particle i
σ_u^2	Power of the interference signal
σ_s^2	Power of the real user signal
rand	Random interval [0, 1]
r_d	Reference signal
$\hat{\mathbf{\Gamma}}$	Sample average covariance matrix
c	Speed of light = 3×10^8 [m/s]
$\tilde{A}$	Steering matrix
s.t.	Subject to
r	The total received signal by the multiple array elements
t	Time index
$F_i^d(t)$	Total force acting on a mass i
V	Velocity vector of particle i
$f_{worst}(t)$	Worst solutions of the objective function at the t^{th} iteration
ε	Zero offset constant

LIST OF ABBREVIATIONS

1D	One-Dimensional
2D	Two-Dimensional
3D	Three Dimensional
4G	Fourth Generation
ABF	Adaptive Beamforming
ACO	Ant Colony Optimization
ADC	Analog/Digital Converter
AOA	Angle of Arrival
AWGN	Additive White Gaussian Noise
BF	Beamforming/Beamformer
BS	Base Station
CDMA	Code Division Multiple Access
CFO	Central Force Optimization
CGM	Conjugate Gradient Method
CMA	Constant Modulus Algorithm
CO	Colony Algorithm
DAS	Delay-and-Sum
dB	Decibel
DE	Differential Evolution
DL	Diagonal Loading
DM-AIS	Dynamic Mutated–Artificial Immune System
DMI	Direct Matrix Inverse
DOA	Direction Of Arrival
DOF	Degree Of Freedom
DSP	Digital Signal Processor
ESPRIT	Estimation of Signal Parameters via Rotational Invariance Techniques
FDMA	Frequency Division Multiple Access
FNBW	First Null BeamWidth
FPGA	Field Programmable Gate Array
GA	Genetic Algorithm

GSA	Gravitational Search Algorithm
HBMO	Honey Bees Mating Optimization
HPBW	Half Power BeamWidth
INR	Interference-to-Noise Ratio
IWO	Invasive Weed Optimization
LAA	Linear Antenna Array
LB	Lower Bound
LCMV	Linearly Constrained Minimum Variance
LM	Lagrange Multiplier
LMS	Least Mean Square
MAI	Multiple Access Interference
MATLAB	Matrix Laboratory
Max-SLL	Maximum Sidelobe Level
MDN	Maximum Depth Null
MIMO	Multiple Input Multiple Output
ML	Maximum Likelihood
MMSE	Minimum Mean Square Error
mp–QP	multi-parametric Quadratic Programming
MSE	Mean Square Error
MUSIC	MUltiple SIgnal Classification
MVDR	Minimum Variance Distortionless Response
$MVDR_{PSOGSA}$	MVDR–PSOGSA beamformer
$MVDR_{ZN}$	MVDR–Zero–Null beamformer
NM	Nelder-Mead
PSO	Particle Swarm Optimization
QoS	Quality-of-Service
RADAR	Radio Detection and Ranging
RED	Recursive Eigen-Decomposition
RF	Radio Frequency
RLS	Recursive Least Squares
SA	Simulated Annealing
SAS	Smart Antenna System
Sc.	Scenario

SDMA	Space-Division Multiple Access
SINR	Signal-to-Interference-Plus-Noise Ratio
SIR	Signal-to-Interference Ratio
SLL	Side Lobe Level
SMI	Sample Matrix Inversion
SNOI	Signal Not Of Interest
SNR	Signal-to-Noise Ratio
SOI	Signal Of Interest
SQP	Sequential Quadratic Programming
TagO	Taguchi's Algorithm
TDMA	Time Division Multiple Access
TS	Tabu Search
UB	Upper Bound
UCA	Uniform Circular Array
UE	User Equipment
ULA	Uniform Linear Array
UOI	User Of Interest
UPA	Uniform Planar Array
URA	Uniform Rectangular Array
ZF	Zero Forcing