

Large Scale Antenna Array for GPS Bistatic Radar

Chow Yii Pui

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School of Electrical and Electronic Engineering
Faculty of Engineering, Computer and Mathematical Sciences
The University of Adelaide
South Australia

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Contents

Abstract	v
Declaration	vii
Acknowledgements	ix
List of Figures	xi
List of Tables	xix
Abbreviations	xxi
Symbols	xxv
Publications	xxix
1 Introduction	1
1.1 Problem Description.....	1
1.2 Outline of Thesis and Main Contributions.....	4
2 GPS Bistatic Radar Background for Target Detection	7
2.1 Introduction	7
2.2 Background of Passive Bistatic Radar	7
2.3 PBRs Performance Comparison.....	10
2.4 Background of GPS.....	11
2.4.1 GPS Signal Detection Techniques.....	13
2.5 GPS Bistatic Radar Detection Applications.....	18
2.6 GPS Signal Air Target Detection for Passive Bistatic Radar	20
2.6.1 Coherent Integration	21
2.6.2 Non-coherent Integration.....	22
2.6.3 Radar Cross-section	23

2.6.4	Phased-array Technique.....	24
2.6.5	MIMO Radar Technique.....	25
2.7	Proposed Research	27
2.7.1	Coherent Integration	27
2.7.2	Phased-array Technique.....	29
2.7.3	MIMO Radar Technique.....	30
2.8	Conclusion.....	30
3	Feasibility of Target Detection using Phased-array Technique	33
3.1	Introduction	33
3.2	Estimation of Parameters for GPS Bistatic Radar.....	34
3.2.1	Power Measurement of Target Scattering	34
3.3	Background of Phased-array Technique	39
3.3.1	Phased-array Receiver for PBR.....	40
3.3.2	Null-Steering.....	43
3.3.3	Discussion of Phased-array Technique for GPS Bistatic Radar.....	43
3.4	Antenna Array Calibration Technique	45
3.4.1	Background.....	45
3.4.2	Phase Error Calibration for GPS Bistatic Radar.....	47
3.4.3	Attitude Calibration of Receiving Array for GPS Bistatic Radar.....	49
3.5	Target Verification and Identification Process.....	50
3.5.1	Target Detection Modelling.....	52
3.5.2	Simulation Example of Target Detection	54
3.5.3	Target Parameter Estimation	60
3.5.4	Simulation Example of Target Parameters Estimation.....	64
3.6	Conclusion.....	71
4	GPS Bistatic Radar using MIMO Technique	75
4.1	Introduction	75
4.2	MIMO Radar Target Detection Model for GPS Bistatic Radar.....	76
4.3	Performance of MIMO Technique for GPS Bistatic Radar	79

4.3.1	Target Detection Performance	80
4.3.2	Target Location Estimation Accuracy	83
4.3.3	Computational Complexity.....	85
4.4	Simulation of Target Detection Results for GPS MIMO Radar	85
4.4.1	Target Detection (SISO vs. MISO)	86
4.4.2	Target Detection (MISO vs. MIMO).....	93
4.4.3	Detection for Multiple Targets (SISO vs MISO vs MIMO).....	98
4.4.4	Target Tracking for GPS MISO/MIMO Radar	101
4.5	Conclusion.....	108
5	Experimental Target Detection Performance for GPS Bistatic Radar	113
5.1	Introduction	113
5.2	Experimental Receiver for Air Search GPS Bistatic Radar	116
5.2.1	Description of Receiver's Design.....	116
5.2.2	Receiver Performance Benchmark	121
5.3	Direct-path Signal Acquisition.....	123
5.4	Experimental Antenna Array Calibration Results.....	130
5.4.1	Antenna Array Deployment.....	130
5.4.2	Calibration Process and Outcome.....	130
5.4.3	Verification of Calibration Results	132
5.5	Direct-path Signal Interference Cancellation Technique	137
5.5.1	Background.....	137
5.5.2	Simulation Examples of DSI cancellation technique	140
5.5.3	Experimental results using DSI cancellation technique	143
5.6	Experimental Results from Air Target Detection	145
5.6.1	Experiment Scenario for Target Detection	145
5.6.2	Phased-array Detection Technique	148
5.6.3	MISO Radar Detection Technique	160
5.7	Conclusion.....	165
6	Conclusion	167

6.1 Summary and Contributions..... 167
6.2 Further Recommendations 170

References **171**

Abstract

GPS passive bistatic radar uses signals transmitted by navigation satellites to perform target detection. This research aims to develop a ground-based receiver that detects the reflected GPS signals from air targets. The main challenge for GPS bistatic radar is the difficulty in detecting the extremely weak power GPS signal reflections from a target since GPS satellites are located at very high altitudes and transmit signals at relatively low power levels.

The research in this thesis investigates the minimum power of the reflected GPS signal that can be reliably detected by applying several techniques for enhancing the receiver detection performance. The proposed techniques for GPS bistatic radar target detection model include: using a large scale antenna array at the receiver, applying long coherent integration times for the captured data and non-coherently summing the power returns of targets from multiple satellites or receivers. This detection model requires the radar system to incorporate the signal information from a large number of receiving channels and non-cooperative transmitters to perform air target detection.

This research also incorporates additional techniques at the pre-detection stage that are essential for the target detection model. Among these techniques include: direct-path GPS signals acquisition that obtains the Doppler frequency component and C/A code pattern from each satellite, array calibration that realigns the inter-element phase errors and orientation of phased-array receiver using the GPS system, and direct-path signal interference cancellation.

The GPS bistatic radar target detection performance was initially investigated using the results produced by computer simulations. Then, a prototype phased-array GPS bistatic radar receiver was built to capture target reflections from an aircraft and investigate the detection performance of the system experimentally. The system was able to successfully detect and locate the position of a nearby aircraft, which demonstrates that the techniques introduced for GPS bistatic radar in this thesis do work in practice. The experimental results also provide a

benchmark that can be used to estimate the scale of the receiver required for detecting objects at a greater distance.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Signature:

Date:

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List of Figures

Figure 1.1: Illustration of monostatic radar vs. bistatic radar.2

Figure 1.2: The PBR airborne target detection environment.3

Figure 2.1: A typical block diagram of GPS receiver.14

Figure 2.2: The illustration of discrete linear code-Doppler search algorithm. The ‘X’ symbol in the grid indicates the code-Doppler location of a GPS signal.17

Figure 2.3: A down-converted GPS signal located at Doppler offset of 1,900 Hz and sampled code phase of 2,866 is sampled at 4.167MHz and detected using code-Doppler search for an integration period of 5 milliseconds and Doppler resolution of 50 Hz.17

Figure 2.4: Schematic of the proposed phased array (Top) and MIMO radar (Bottom) designs for GPS bistatic radar in performing air target detection and parameters estimation.28

Figure 3.1: Target detection scenario of a bistatic radar (not to scale).34

Figure 3.2: Estimated return power (Left) and SNR (Right) of various RCS targets.36

Figure 3.3: Given a certain CFAR, a higher SNR of the input signal results in an improvement of receiver performance in terms of probability of detection.38

Figure 3.4: Required GPS bistatic radar receiver gain for detecting targets of various RCS, σ_B , while satisfying detection performance of $\mathbb{P}_D = 90\%$ and $\mathbb{P}_{FA} = 1\%$38

Figure 3.5: Illustration of the arrival of plane wave signals at antenna array.41

Figure 3.6: Beam pattern of a 8-element ULA showing 2 null directions using the null-steering technique.44

Figure 3.7: Geometry of phased-array antenna panel in 3-D coordinates.48

Figure 3.8: Orientation of phased-array panel with respect to the original configuration.48

Figure 3.9: Satellite tracking program "JSatTrak" showing the orbit (Top), range, azimuth and elevation angles information (Bottom Left) and polar plot (Bottom Right) of GPS PRN02 from a receiver position near Adelaide airport (Courtesy Shawn Gano).48

Figure 3.10: Flowchart of the attitude calibration process for a receiving array incorporating the LSE for determining the inter-channel phase errors.51

Figure 3.11: Normalised CAF of GPS bistatic radar from simulation search process using integration process of 10, 30 and 100 C/A code periods (Top to bottom).....	57
Figure 3.12: Correlation value at 1st sample delay vs. frequency difference at output of single element vs. 32-element receiver.	58
Figure 3.13: Beampower of 32-element receiver for target scattering signal at $f_{\delta} = -170$ Hz and $k_{\delta} = 1$. The maximum power appears at a target DOA of $\theta_{\delta} = 54^{\circ}$ and $\phi_{\delta} = 45^{\circ}$	59
Figure 3.14: CCAF from a GPS bistatic radar single target detection scenario (Sim 1).	59
Figure 3.15: CCAF from a GPS bistatic radar single target detection scenario (Sim 2).	60
Figure 3.16: Normalised CCAF processed from simulation in a GPS bistatic radar multiple targets detection scenario using transmitter PRN12 (Left) and PRN24 (Right).....	66
Figure 3.17: Beampower of target 1 return using detection from PRN12 and PRN24. The peaks of both results indicate the DOA of target at $\theta = 45^{\circ}$ and $\phi = 55^{\circ}$	66
Figure 3.18: Beampower of target 3 return using detection from PRN12 and PRN24. The peak of both results indicate the DOA of target at $\theta = 90^{\circ}$ and $\phi = 56^{\circ}$	66
Figure 3.19: BCAF results (PRN12) of target 1/2 and 3 that are performed during the target tracking process using the conventional beamforming technique.	68
Figure 3.20: BCAF results (PRN12) of target 1/2 and 3 that are performed during the target racking process using the MVDR beamforming technique.	68
Figure 3.21: BCAF results (PRN12) of target 1/2 and 3 that are performed during the target tracking process using the null-steering technique.	68
Figure 3.22: Correlation function that is performed using original vs. interpolated signals. Note that the correlation value is normalised and the sample delay axis is applied with the time scale of interpolated signals. The peak of correlation for PRN04, PRN12, PRN23 and PRN24 appear at sample delay bin of 123, 157, 140 and 41 respectively.	70
Figure 3.23: Inverse MSE of localisation for target 3 determined from model (3.51) using sampling delay from original (Left) vs. interpolated (Right) correlation results. The largest inverse MSE of these results appear at position of [38, 174, 95] and [0, 150, 97] metres relative to the radar receiver respectively.	70
Figure 3.24: Inverse MSE of localisation for target 3 determined from model (3.53) using its corresponding Doppler readings from BCAF results (Top Left) and the 3-D velocity diagrams estimated by LSE at position bins within the search range.	72
Figure 4.1: Illustration of target detection scenario for GPS MISO radar.....	77
Figure 4.2: Block diagram of GPS MISO radar system (Top) that combines the output from L satellites. The function of the matched filters (Bottom) within the system is also illustrated.	78

Figure 4.3: Block diagram of GPS MIMO radar system that combines the output from B MISO receivers.	80
Figure 4.4: The probability of detection vs. pre-integrator stage SNR using different numbers of non-coherent integration.	82
Figure 4.5: Comparison of gain level at different numbers of integration.	82
Figure 4.6: Simulated geolocation of target detection (4TX and 1RX). Note that the unit ‘Mm’ denotes Mega (10^6) metre.	87
Figure 4.7: Target location estimation results (normalised) from $L \times 1$ GPS MISO radar systems with 10 m search resolution using integration of different numbers of SV.	87
Figure 4.8: Errors between the magnitudes of true target velocity (i.e. 54.78 m/s) and the readings from the measurements of $L \times 1$ GPS MISO radar target location estimation results.	89
Figure 4.9: Histograms of $\mathcal{H}0$ and $\mathcal{H}1$ compared with the theoretical chi-squared and non-central chi-squared PDFs model respectively for $L \times 1$ GPS MISO configurations.	90
Figure 4.10: Comparison of CDFs for different numbers of non-coherent integration between the histograms given by the MCE of MISO detection results (o) and the theoretical chi-squared models (continuous lines).	90
Figure 4.11: Comparison of pRMSE and vRMSE measurements obtained from the MCE between $L \times 1$ MISO configurations at different input SNR levels.	92
Figure 4.12: Simulated geolocation of target detection (4TX and 4RX).	93
Figure 4.13: Target location estimation results (normalised) from GPS $L \times B$ MIMO radar with 10 m search resolution using integration of different numbers of receivers.	95
Figure 4.14: Errors between the magnitudes of true target velocity (54.78 m/s) and the readings from the measurements of $L \times B$ GPS MIMO radar target location estimates.	95
Figure 4.15: Histograms of $\mathcal{H}0$ and $\mathcal{H}1$ compared with the theoretical chi-squared and non-central chi-squared PDFs model respectively for $L \times B$ GPS MIMO configurations.	95
Figure 4.16: Comparison of CDFs for different numbers of non-coherent integration between the histograms given by the MCE of MIMO detection results (o) and the theoretical chi-squared models (continuous lines).	96
Figure 4.17: Comparison of pRMSE and vRMSE measurements obtained from the MCE between 4×1 MISO, 4×2 and 4×4 MIMO configurations at different input SNR levels.	97
Figure 4.18: Simulated geolocation of target detection (4TX, 4RX and 3 targets).	98

Figure 4.19: Position estimation and velocity error results of multiple targets (normalised) from GPS SISO/MISO radar systems with 10 m search resolution using the 1×1, 2×1 and 4×1 configurations.	99
Figure 4.20: Position estimation results of multiple targets (normalised) from GPS MIMO radar systems with 10 m search resolution using the 4×2 and 4×4 configurations.	100
Figure 4.21: Simulated geolocation of target detection (4TX, 1RX and 3 targets).	102
Figure 4.22: Variations in targets positions, Doppler frequency, sample delays and DOAs due to their corresponding motions in 100 ms.....	102
Figure 4.23: Illustration of matched filter for tracking target in the detection process using the TBD (Top) and integration with fragmentised data samples (Bottom) methods.....	103
Figure 4.24: MIMO radar target location estimation results (normalised) at 10 m search resolution (Top Left) and their corresponding 3-D velocity components using the TBD technique. The velocity vector estimates for all identified targets are [50; 20; -10], [500; 200; -10] and [2000; 2000; 0] m/s respectively.	105
Figure 4.25: MIMO radar target location estimation results (normalised) at 10 m search resolution using the integration of the first sub-block fragmentised data of 10 ms, 25 ms, 50 ms and full integration process of 100 ms (i.e. no fragmentation).	106
Figure 4.26: The sequence of MIMO radar target location estimation results (normalised) at 10 m search resolution using the integration of 25 ms fragmentised data sub-blocks out of 100 ms data snapshot.....	107
Figure 4.27: The 2-D velocity result corresponding to the integration of fragmentised data sub-block 0 - 25 ms.....	107
Figure 4.28: The true target path and the recorded target (Tgt2) positions where peak returns appeared at all the time frames using the fragmentised data integration of various sub-block lengths out of 100 ms data snapshot.	109
Figure 4.29: Performance chart of tRMSE vs. integration sub-block lengths.	109
Figure 5.1: Overall process of GPS bistatic radar system for performing target detection. ..	114
Figure 5.2: Outline of the experimental GPS bistatic radar receiver.	117
Figure 5.3: Picture of the front-end's PCB.	117
Figure 5.4: Picture of the 32-elements array and the schematic of the 8-element circular grid sub-array (Courtesy of Opt-Osl Systems).....	118
Figure 5.5: Comparison of beam pattern of 8-element sub-array ($\theta_s = 0^\circ$, $\phi_s = 45^\circ$).....	119
Figure 5.6: Comparison of beam pattern of 32-element antenna array ($\theta_s = 0^\circ$, $\phi_s = 45^\circ$). ...	119

Figure 5.7: Illustration of data captured from 4 FPGAs stored into PC, translated into decimal complex numbers form and sorted into 64 blocks based on the configuration of antennas in the array.	121
Figure 5.8: Analysis of GPS signal correlation sample lag across time and its rate of change modelling using linear regression method. Note that PRN12 and PRN24 possess a negative (-4.1 Hz) and positive (3.6 Hz) Doppler respectively.	125
Figure 5.9: Phase analysis of GPS signal after the removal of C/A codes decimation filtering. Each phase change of π radians in the figures indicates a data-bit transition of the navigation message.	126
Figure 5.10: Phase reading of residual Doppler component in the GPS signal.	127
Figure 5.11: Comparison of the signal phase of PRN12 after residual Doppler removal modelled by various polynomial orders. The variances of these phase readings in the ascending polynomial order are 0.0051, 0.0049, 0.0046 and 0.0043. These parameters show that a slightly smoother phase reading is achieved as the time varying Doppler component is removed using higher order polynomial regression modelling.	127
Figure 5.12: Phase reading of residual Doppler component in the GPS signal.	128
Figure 5.13: Comparison of the signal phase of PRN24 after residual Doppler removal modelled by various polynomial orders. The variances of these phase readings in the ascending polynomial order are 0.0307, 0.0175, 0.0170 and 0.0168. These parameters show a significantly smoother phase reading is achieved as the time varying Doppler component is removed using the polynomial regression modelling.	128
Figure 5.14: Block diagram of navigation message and residual Doppler component extraction from a GPS signal.	129
Figure 5.15: Illustration of the GPS bistatic radar receiver's deployment for the air target detection experiment (Courtesy Google Map's satellite view).	131
Figure 5.16: Phase measurement of direct-path signals correlation peaks at 62 channels from 5 GPS satellites (PRN12, 14, 24, 25 and 29).	131
Figure 5.17: Normalised inverse MSE determined by the array attitude calibration process. The highest inverse MSE value was located at $\phi_e = -42.5^\circ$ & $\theta_e = 183.5^\circ$	133
Figure 5.18: Antenna positions relative to the reference before attitude correction, \mathbf{u} , and after attitude correction, \mathbf{u}'	133
Figure 5.19: Normalised correlation values (dB scale) of phased-array receiver vs single channel from every element using an integration length of 980 ms (PRN12 & PRN24).	134

Figure 5.20: Peak correlation value (dB scale) of each channel relative to their phased-array correlation peak (PRN12 & PRN24) at zero sampled code phase.....	134
Figure 5.21: Comparison of direct-path signals acquisition results between a single (reference element) and beamformer: Phase readings of data after the removal of C/A codes PRN02 (Left); Coarse Doppler search for GPS signal PRN04 (Right).	135
Figure 5.22: Normalised beampowers (dB scale) vs. DOA of PRN04, 12 and 14 from the phased-array GPS receiver DOA search process with an angle resolution of 1° for both θ and ϕ	136
Figure 5.23: Illustration of a Wiener filter for estimating and cancelling the interferences from the captured data.	140
Figure 5.24: Normalised CAF results from a simulation detection process without Wiener filter (Top), with Wiener filter to remove the DSIs only (Middle) and to remove both DSIs and their multipath (Bottom). Both the CAFs from the Wiener filter are compressed to a dynamic range of 30 dB.....	142
Figure 5.25: Squared correlation results (dB) for PRN02 and PRN24 from the beamformer's output applying (i) No filter; Wiener filter for DSI cancellation with number of taps, $\mathfrak{M} =$ (ii) 20, (iii) 40 and (iv) 60.	144
Figure 5.26: Experiment scenario (Courtesy Google Map's satellite view).....	146
Figure 5.27: Deployment of phased-array receiver (Left); Power supply and data acquisition PC for the receiver system (Right).....	146
Figure 5.28: Pictures of landing aircraft extracted from the footage recorded by a digital video camera at the target detection experiment site.	147
Figure 5.29: Positions of GPS satellites during the aircraft detection experiment.	148
Figure 5.30: Normalised CCAF results of PRN02, 04, 12 and 24 from the experiment detection process for data period 200 - 300 ms.	149
Figure 5.31: Normalised beampower of peak returns from the CCAF results of PRN02, 04, 12 and 24 for data period 200 - 300 ms.	150
Figure 5.32: Normalised beampower of 3 rd peak return from the CCAF result of PRN24 for data period 200 - 300 ms. The DOA for the highest beampower is indicated.....	150
Figure 5.33: Normalised beampower results of peak return from the CCAF results of PRN02 along the captured data. Among the results are those from frame 1, 3, 5 and 8.....	152
Figure 5.34: Comparison of flight path and the azimuth angles measured from the beamformer results of PRN02 along the captured data of approximately 1000 ms. Google Earth was used to perform the angles and distance measurements.....	152

Figure 5.35: Variations of azimuth and elevation angles corresponding to the peak returns from PRN02, 04 and 24 at different time.	153
Figure 5.36: Normalised BCAF results of PRN02, 04, 12, 24, 25 and 29 from the experiment detection process for data period 200 - 300 ms at $\phi_d = 63^\circ$ and $\theta_d = -157^\circ$	154
Figure 5.37: Normalised inverse 2-D position MSE results estimated by the TDOAs from 4, 5 and 6 satellites. The red lines resemble the flight path determined from Google Earth.	157
Figure 5.38: Normalised inverse 2-D position MSE results estimated by the Doppler offsets from 4, 5 and 6 satellites. The red lines represent the flight path determined from Google Earth.	158
Figure 5.39: Normalised 2-D target positioning results from frame 3, 6, 9, 12, 15 and 18 at 50 m altitude using 7×1 MISO configuration (i.e. PRN02, 04, 12, 14, 24, 25 and 29). Each frame represents the result processed from the data integration process of 50 ms and 10 m search position resolution. The red lines represent the predicted flight path.	162
Figure 5.40: SNR of target return peaks at different time for MISO configurations: 4×1 , 5×1 , 6×1 and 7×1 . Note that the 6×1 results are overlapped by the 7×1 results due to their extremely small SNR differences across the whole data block. The average SNR for each configuration is recorded in the legend box.	163
Figure 5.41: Results of various MISO configurations showing the 2-D positions of peak target returns from different time frames at 50m altitude. The red lines represent the predicted flight path.	164

List of Tables

Table 3.1: List of simulation cases using different expected target SNR.....	56
Table 3.2: Positions of targets and transmitters relative to the radar receiver.....	64
Table 3.3: Rounded number of samples (time in picoseconds) delays of target returns relative to direct-path signals.....	65
Table 3.4: Measured parameters of each return from the detection process.....	67
Table 3.5: Summary of parameters for target 3 from simulated detection and estimation.....	71
Table 4.1: Summary of the input and pre-integrator SNR for various MISO configurations.....	88
Table 4.2: Summary of the input and pre-integrator SNR for MIMO configurations.....	94
Table 4.3: Summary of the normalised correlation values between Tgt1 and Tgt2 using the fragmented integration process of various lengths.....	105
Table 5.1: Specification chart for essential parameters of the experimental GPS bistatic radar.....	116
Table 5.2: Summary of target detection range for a 32-element GPS bistatic radar receiver.....	122
Table 5.3: Summary of DOA of GPS satellites to the GPS bistatic radar receiver.....	132
Table 5.4: Comparison of DOA readings between the results from ephemeris information and the beamformer's search process.....	135
Table 5.5: Summary of signal parameters for DSI cancellation simulation case.....	141
Table 5.6: SNR of target return peaks from 6 GPS satellites at data period 200-300 ms.....	155
Table 5.7: List of PRNs applied for each MSE configuration.....	156
Table 5.8: Comparison of target velocity between the estimations from the predicted from the flight path and the results from the MSE solution.....	159
Table 5.9: Comparison between the target parameters determined by simulation and experiment.....	160
Table 5.10: List of PRNs applied for each MISO configuration and their average SNRs. ...	161
Table 5.11: Target velocity determined by the MISO positioning results.....	164

Abbreviations

2-D/3-D	Two/Three-dimensional space
ADC	Analogue-to-digital converter
ARM	Anti-radiation missile
AWGN	Additive white Gaussian noise
BCAF	Cross ambiguity function (Beamformer)
BDS	BeiDou navigation satellite system
BPSK	Binary phase-shift keying
C/A	Coarse/acquisition
CAF	Cross ambiguity function
CCAF	Cross ambiguity function (Combined elements)
CDF	Cumulative distribution function
CDMA	Code division multiple access
CFAR	Constant false alarm rate
CRPA	Controlled radiated pattern antenna
CW	Continuous wave
DAB	Digital audio broadcasting
DOA	Direction-of-arrival
DOP	Dilution of precision
DSI	Direct-path signal interference
DSP	Digital signal processor
DSSS	Direct-sequence spread spectrum
DVB-S	Digital video broadcasting-Satellite
DVB-T	Digital video broadcasting-Terrestrial
ECM	Electronic countermeasure
EIRP	Effective isotropic radiated power
FDOA	Frequency-difference-of-arrival

FFT	Fast Fourier transform
FIFO	First in, first out
FM	Frequency modulation
FPGA	Field-programmable gate arrays
FRPA	Fixed radiated pattern antenna
GEMS	GNSS environment monitoring system
GNSS	Global navigation satellite system
GPS	Global Positioning System
GSM	Global system for mobile communications
HDOP	Horizontal dilution of precision
IF	Intermediate frequency
JPALS	Joint precision approach and landing system
LEO	Low Earth orbit
LHCP	Left-hand, circularly polarized
LNA	Low noise amplifier
LOS	Line-of-sight
LP	Linearly polarised
LSE	Least squares estimator
MCE	Monte Carlo experiments
MEO	Medium Earth orbit
MIMO	Multiple-input & multiple-output
MISO	Multiple-input & single-output
MMSE	Minimum mean square error
MSE	Mean squared error
MVDR	Minimum variance distortionless response
PBR	Passive bistatic radar
P	Precision
PC	Personal computer
PDF	Probability density function
PDOP	Position dilution of precision
PLL	Phased-locked loop
PMR	Passive MIMO radar
PRN	Pseudo-random noise
RCS	Radar cross-section

RF	Radio frequency
RHCP	Right-hand, circularly polarised
RMSE	Root-mean-square error
SDRAM	Synchronous dynamic random access memory
SISO	Single-input & single-output
SNR	Signal-to-noise ratio
SV	Space vehicle
TBD	Track-before-detect
TDOA	Time-difference-of-arrival
TOA	Time-of-arrival
UERE	User equivalent range error
VDOP	Vertical dilution of precision
VHDL	VHSIC hardware description language
VHSIC	Very high speed integrated circuit

Symbols

x^*	complex conjugate
x^T	transpose
x^H	Hermitian/conjugate transpose
$f(t)$	continuous function
$f(k)$	discrete function
$n(t), n(k)$	white noise
\mathbf{a}	array steering vector
b	receiver index
c	speed of light
f_B	signal bandwidth
f_0	signal carrier frequency
f_D	direct-path signal Doppler frequency
f_δ	target Doppler frequency
\mathcal{F}	function of Doppler frequency
j	complex number
k	sample index
k	Boltzmann constant
\mathbb{k}	data sub-block time frame index
l	transmitter/satellite index
m	antenna element index
m	multipath signal index
n	noise
\mathbf{p}	position vector
\mathbf{u}	coordinate of sensor's element relative to reference
\mathbf{v}	velocity vector
\mathbf{w}	weigh vector

B	number of base stations/receiver sites
$C(t), C(k)$	PRN code sequence
$\mathcal{C}(k, \mathbf{p}_\delta)$	function of PRN code sequence
$E(H)$	expectation of random variable
G	gain
\mathcal{H}	hypothesis of a statistical model
I	identity matrix
K	number of samples
\mathbb{K}	total number of data sub-blocks
\bar{K}	size of each data sub-block
L	number of illuminators/satellites
M	number of antenna elements
\mathfrak{M}	number of multipath signals
\mathcal{N}	number of Monte Carlo experiments
P_x, P_y, P_z	position search range in x , y and z dimensions
\mathbb{P}	probability
\mathcal{P}	subspace projection of signals
P_R	receiving power at the receiver
P_T	transmitting power of illuminator
R_D	direct propagation path
R_T	transmitter-to-target/transmission path
R_R	receiver-to-target/reflected path
$\mathcal{R}(t), \mathcal{R}(k)$	Cross-correlation function
RX	receiver
TX	transmitter
V_x, V_y, V_z	velocities search range in x , y and z dimensions
V	velocity magnitude
Γ	Gamma function
Λ	chi-squared distribution non-centrality parameter
α	number of beams
β	bistatic angle
γ	lower incomplete Gamma function
δ	target index

ϵ	inter-element phase error
θ	azimuth angle
λ_0	signal wavelength
ρ	pseudorange
ψ	target velocity aspect angle
μ	signal amplitude
σ	noise amplitude
σ_B	bistatic radar cross section
τ	detection threshold
ϕ	elevation angle

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