Weak Interference Direction of Arrival Estimation in the GPS Frequency Band

by

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Abstract

The GPS signal is vulnerable to both intentional and unintentional interferences due to its low received power. The need to localise GPS interference sources is becoming more pressing as more systems rely on GPS, while GPS jammers are becoming more widely available. This thesis discusses techniques to estimate the direction of arrival (DOA) of weak interferences in the GPS frequency band using antenna arrays.

The main issues which affect weak GPS interference DOA estimation accuracy are the antenna array errors, interference from other GPS signals, the number of snapshots required for DOA estimation and system coloured noise.

In order to estimate antenna array errors, a modelled eigenstructure based antenna array calibration algorithm is presented. This algorithm describes the antenna array errors using a physical model and uses the GPS signals with known DOAs as disjoint calibration sources to reduce the number of unknown calibration parameters and to enable a larger number of possible calibration sources to be used.

GPS calibration sources often have multipath components. These multipath components will contaminate the mutual coupling estimation result due to a similar directional behaviour. In order to solve this issue, a new calibration algorithm is developed to estimate the mutual coupling matrix in the presence of multipath signals. This algorithm first uses the decomposed signal subspace to construct its calibration cost function and then estimates the calibration parameters using alternating projection based methods iteratively.

The GPS signals typically have a SNR range from -15dB to -30dB. If the INR of the weak GPS interference is close or lower than this range, GPS signals need to be mitigated as they act like strong interferences. A Multiple

Subspace Projection (MSP) algorithm is proposed to cancel GPS signals. This algorithm projects the received signal onto the orthogonal subspace of GPS signals to cancel them completely even if the signals are band-limited, have multipath components, or have fractional delays.

The number of snapshots in the received data significantly influences the DOA estimation variance. The Cramer-Rao Lower Bound (CRLB) is derived and analysed for the antenna array DOA estimation. By using the CRLB, the number of snapshots is required to be larger than 1×10^6 to have the DOA estimation standard deviation to be smaller than 0.25º for a signal with a SNR of -20dB.

Finally, after cancelling GPS signals using the MSP algorithm, whitening the coloured noise in the system by using noise only data and calibrating the antenna array, the experimental results using an eight-element GPS antenna array showed that the DOA of a weak GPS interference with a SNR of -22dB could be accurately estimated.

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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Abbreviations

ADC:	Analog-to-Digital Converter
AGC:	Automatic Gain Control
AP:	Alternating Projections
BF:	Beamformer
BPSK:	Binary Phase Shift Keying
C/A:	Coarse/Acquisition Code
CBF:	Conventional Beamformer
C/No:	Carrier-to-Noise ratio
CRLB:	Cramer-Rao Lower Bound
CW:	Continuous Wave
DOA:	Direction of Arrival
DS-SS:	Direct Sequence-Spread Spectrum
ESPRIT:	Estimation of Signal Parameter via Rotational Invariance Techniques
FIM:	Fisher Information Matrix
FIR:	Finite Impulse Response
GNSS:	Global Navigation Satellite System
GPS:	Global Positioning System
INR:	Interference-to-Noise Ratio
LF:	Likelihood Function
LPF:	Low Pass Filter
LS:	Least Squares
L1:	L1 Frequency Band, 1575.42MHz

L2: L2 Frequency Band, 227.6MHz

MaxSINR: Maximum Signal-to-Interference and Noise Ratio

ML: Maximum Likelihood

MMSE: Minimum Mean Square Error

MUSIC: Multiple Signal Classification

MVDR: Minimum Variance Distortionless Response

NCO: Numerically Controlled Oscillator

PRN: Pseudo Random Noise

RF: Radio Frequency

RFI: Radio Frequency Interference

RHCP: Right Hand Side Circularly Polarisation

RMSE: Root Mean Squared Error

SINR: Signal-to-Interference and Noise Ratio

SNR: Signal-to-Noise Ratio

STD: Standard Deviation

SV: Space Vehicle

UCA: Uniform Circular Array

ULA: Uniform Linear Array

Publications

The list of publications related to this thesis are:

- Z. Xu, M. Trinkle, and D. A. Gray, "A modelled eigenstructure based antenna array calibration algorithm for GPS," in *Proceedings of the 23rd International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2010)*, Portland, OR, 2010, pp. 3220-3228.

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