

The Constrained Conjugate Gradient Algorithm

J. A. Apolinário, Jr., *Member, IEEE*, M. L. R. de Campos, *Member, IEEE*, and C. P. Bernal O.

Abstract—Based on the condition for equivalence between linearly constrained minimum-variance (LCMV) filters and their generalized sidelobe canceler (GSC) implementations, we derive the new constrained conjugate gradient (CCG) algorithm. We discuss the use of orthogonal and nonorthogonal blocking matrices for the GSC structure and how the choice of this matrix may affect the relationship with the LCMV counterpart. The newly derived algorithm was tested in a computer experiment for adaptive multuser detection and showed excellent results.

Index Terms—Conjugate gradient algorithms, constrained adaptive filtering.

I. INTRODUCTION

LINEARLY constrained adaptive filters have been used in many applications including adaptive beamforming with sensor arrays and blind adaptive interference cancellation in multuser mobile communication systems. The constrained version of the least mean square (LMS) algorithm (CLMS) was proposed in [1] for the minimization of the output-error energy of a finite impulse response (FIR) filter subject to a set of known linear constraints, i.e., $\min_w E\{e^2\}$ subject to $\mathbf{C}^T \mathbf{w} = \mathbf{f}$, where \mathbf{w} is the length M coefficient vector, e is the filter output error, \mathbf{C} is the $M \times p$ constraint matrix, and \mathbf{f} is the length p gain vector. In [2], an alternative structure was presented whereby only a smaller set of coefficients are updated, which are confined to the subspace orthogonal to the space spanned by the constraint matrix \mathbf{C} . This structure, known as the generalized sidelobe canceler (GSC), is able to transform the linearly constrained minimization problem into an unconstrained minimization problem, and therefore can accommodate virtually any adaptation algorithm. Although the constrained algorithm and its GSC implementation are assumed to present identical steady-state performance [2] in a stationary environment, different choices of the blocking matrix \mathbf{B} such that $\mathbf{B}^T \mathbf{C} = \mathbf{0}$ leads to different results. Moreover, this matrix determines the computational complexity of the adaptation algorithm implemented in the GSC structure. This paper revisits the condition of equivalence between a constrained adaptive filter and its GSC counterpart and uses this condition to introduce a new constrained algorithm, the constrained conjugate gradient (CCG) algorithm.

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II. PRELIMINARIES

The CLMS solution to the linearly constrained minimum-variance (LCMV) problem is given by [1]

$$\mathbf{w}(k+1) = \mathbf{P}\mathbf{w}(k) - \mu y(k) \mathbf{P} \mathbf{x}(k) + \mathbf{F} \quad (1)$$

where

$$\begin{aligned} \mathbf{F} &= \mathbf{C}(\mathbf{C}^T \mathbf{C})^{-1} \mathbf{f}, \\ \mathbf{P} &= \mathbf{I} - \mathbf{C}(\mathbf{C}^T \mathbf{C})^{-1} \mathbf{C}^T \end{aligned}$$

projection matrix onto the subspace orthogonal to the subspace spanned by the constraint matrix, and the output signal;

$y(k)$ = $\mathbf{w}^T(k) \mathbf{x}(k)$, output signal.
 $\mathbf{x}(k)$ is the input-signal vector containing present and past input-signal samples $[x(k) \ x(k-1) \ \dots \ x(k-M+1)]^T$. We recall the fact that although $\mathbf{P}\mathbf{w}(k) + \mathbf{F}$ corresponds to $\mathbf{w}(k)$ in infinite precision, the computation as in (1) is necessary in a limited-precision-arithmetic machine in order to avoid any drift from the constraint plane [1].

The GSC decomposes the coefficient vector by using a transformation matrix given by $\mathbf{T} = [\mathbf{C}; \mathbf{B}]$ where \mathbf{B} is called blocking matrix, and it spans the null space of the constraint matrix \mathbf{C} . The GSC-transformed coefficient vector in $\mathbf{w}(k) = \mathbf{T}\mathbf{w}(k)$ is partitioned as $\mathbf{w}(k) = [\mathbf{w}_U^T; -\mathbf{w}_L^T]^T$, where the upper part is constant and chosen such that $\mathbf{C}\mathbf{w}_U$ corresponds to $\mathbf{F} = \mathbf{C}(\mathbf{C}^T \mathbf{C})^{-1} \mathbf{f}$, and $-\mathbf{w}_L = \mathbf{w}_{\text{GSC}}(k)$ is updated according to an unconstrained adaptive filter such that the overall coefficient vector corresponds to $\mathbf{w}(k) = \mathbf{F} - \mathbf{B}\mathbf{w}_{\text{GSC}}(k)$.

The inverse of the GSC transformation matrix (guaranteed by linearly independent columns of \mathbf{B} and \mathbf{C} , and by $\mathbf{B}^T \mathbf{C} = \mathbf{0}$ [3]) can be partitioned as $\mathbf{T}^{-1} = [\mathbf{A}_1^T; \mathbf{A}_2^T]^T$ where $\mathbf{A}_1 = (\mathbf{C}^T \mathbf{C})^{-1} \mathbf{C}^T$ and $\mathbf{A}_2 = (\mathbf{B}^T \mathbf{B})^{-1} \mathbf{B}^T$.

By replacing \mathbf{A}_1 and \mathbf{A}_2 in \mathbf{T}^{-1} and then in $\mathbf{T}\mathbf{T}^{-1} = \mathbf{I}$, we find another expression for the projection matrix \mathbf{P} , as obtained in [4]

$$\mathbf{P} = \mathbf{B}(\mathbf{B}^T \mathbf{B})^{-1} \mathbf{B}^T. \quad (2)$$

III. EQUIVALENCE CONDITION REVISITED

In this section, we obtain the CLMS algorithm from its GSC implementation in order to find under which circumstances they are equivalent in infinite precision. The GSC coefficient-vector update equation using the LMS algorithm relates to the coefficient-vector update equation for the constrained LMS algorithm according to

$$\begin{aligned} \mathbf{w}(k+1) &= \mathbf{F} - \mathbf{B}[\mathbf{w}_{\text{GSC}}(k+1)] \\ &= \mathbf{F} - \mathbf{B}[\mathbf{w}_{\text{GSC}}(k) + \mu e_{\text{GSC}}(k) \mathbf{x}_{\text{GSC}}(k)] \end{aligned} \quad (3)$$

A Conjugate Gradient Algorithm For Analysis Of Variance

L Cohen



A Conjugate Gradient Algorithm For Analysis Of Variance:

A Conjugate Gradient Algorithm for Analysis of Variance Computations Byung Chun Kim,1984 **Fitting Linear Models** A. McIntosh,2012-12-06 The increasing power and decreasing price of small computers especially personal computers has made them increasingly popular in statistical analysis The day may not be too far off when every statistician has on his or her desktop computing power on a par with the large mainframe computers of 15 or 20 years ago These same factors make it relatively easy to acquire and manipulate large quantities of data and statisticians can expect a corresponding increase in the size of the datasets that they must analyze Unfortunately because of constraints imposed by architecture size or price these small computers do not possess the main memory of their large cousins Thus there is a growing need for algorithms that are sufficiently economical of space to permit statistical analysis on small computers One area of analysis where there is a need for algorithms that are economical of space is in the fitting of linear models **Non-orthogonal Analysis of Variance Using a Generalized Conjugate Gradient Algorithm** Stanford University. Computer Science Department. Numerical Analysis Project,G. H. Golub,S. G. Nash,1980 **An Algorithm for Unbalanced Multifactorial ANOVA Models with Contrasts** Hongsuk Jorn,1986 *Collected Algorithms from ACM.* ,1989 A collation of all algorithms including certifications and remarks that have appeared in the Algorithms Department of Communications of the ACM since 1960 *Proceedings of the Statistical Computing Section* American Statistical Association. Statistical Computing Section,1983 **Realizing Teracomputing** Walter Zwiefelhofer,Norbert Kreitz,2003 Geosciences and in particular numerical weather prediction are demanding the highest levels of available computer power The European Centre for Medium Range Weather Forecasts with its experience in using supercomputers in this field organizes every other year a workshop bringing together manufacturers computer scientists researchers and operational users to share their experiences and to learn about the latest developments This book provides an excellent overview of the latest achievements in and plans for the use of new parallel techniques in meteorology climatology and oceanography The proceedings have been selected for coverage in Index to Scientific Technical Proceedings ISTP CDROM version ISI Proceedings **Journal of the American Statistical Association** ,2006 **Proceedings of the International Conference on Geomechanics and Numerical Simulation (ICGNS 2025)** Yuan Wang,Huaining Ruan,2026-02-09 This book gathers the latest research and practical innovations that tackle critical issues in geotechnical design hazard mitigation and intelligent simulation Advances in geomechanics and computational methods are transforming how engineers and researchers address infrastructure safety and resilience By linking theoretical progress with engineering practice it delivers actionable insights for improving system reliability and reducing risks to communities The book explores three major themes The first focuses on geomechanics and constitutive modeling analyzing the behavior of geomaterials under varied environmental and loading conditions Both established approaches such as elastoplasticity and critical state soil mechanics and advanced multi field coupling models are

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