

Research Article

Engineering Design by Geometric Programming

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A geometric program (GP) is a type of mathematical optimization problem characterized by objective and constraint functions, where all functions are of signomial form. The importance of GP comes from two relatively recent developments: (i) new methods can solve even large-scale GP extremely efficiently and reliably; (ii) a number of practical problems have recently been found to be equivalent to or approximated by GP. This study proposes an optimization approach for solving GP. Our approach is first to convert all signomial terms in GP into convex and concave terms. Then the concave terms are further treated with the proposed piecewise linearization method where only $\lceil \log_2(m-1) \rceil$ binary variables are used. It has the following features: (i) it offers more convenient and efficient means of expressing a piecewise linear function; (ii) fewer 0-1 variables are used; (iii) the computational results show that the proposed method is much more efficient and faster than the conventional one, especially when the number of break points becomes large. In addition, the engineering design problems are illustrated to evaluate the usefulness of the proposed methods.

1. Introduction

Consider the following geometric program (GP) [1]:

$$\min f_0(x) \quad (1)$$

$$\text{s.t. } f_k(x) \leq 1, \quad k = 1, 2, \dots, p, \quad (2)$$

$$g_l(x) = 1, \quad l = 1, 2, \dots, q, \quad (3)$$

$$x = (x_1, x_2, \dots, x_n), \quad (4)$$

where $g_l(x)$, $l = 1, 2, \dots, q$, are monomials as in (5), $c_i \geq 0$, and the exponential constants $\alpha_{di} \in \mathbb{R}$, $i = 1, 2, \dots, n$, $l = 1, 2, \dots, q$:

$$g_l(x) = c_l \prod_{i=1}^n x_i^{\alpha_{di}} \quad (5)$$

and $f_k(x)$, $k = 0, 1, \dots, p$, are posynomials as in (6) which are sum of one or more monomials, $c_{dk} \geq 0$, and $\alpha_{dk} \in \mathbb{R}$, $i = 1, 2, \dots, n$, $k = 0, 1, \dots, p$:

$$f_k(x) = \sum_{d=1}^{D_k} c_{dk} \prod_{i=1}^n x_i^{\alpha_{dk}}. \quad (6)$$

GP has been applied in many fields of applications including analog/digital circuit design [2–8], chemical engineering [9–11], mechanical engineering [12–19], power control [20], and communication network systems [21–23].

Obtaining the optimal solutions for GP is not straightforward because the signomial terms in the objective function and constraints cannot be solved directly. As a result, many approaches have been developed. Coello and Cortés [24] proposed a genetic algorithm with an artificial immune system to solve a GP in engineering optimization. Nevertheless, this method can only obtain the local optima. Horst and Tuy [25] introduced an analytical approach for solving a problem with Lipschitzian objective and constraints. The restriction of this approach is to find the global optimum only if the range of variables can be reduced by analytical techniques. Serali and Tuncbilek [26] developed a reformulation-linearization technique (RLT) which generates polynomial implied constraints and then linearizes the resulting problem by introducing new variables. Lin and Tsai [14] introduced a generalized method to find multiple optimal solutions of signomial discrete programming problems with free variables. By means of variable substitution and convexification strategies, a signomial discrete programming problem with free variables is

Engineering Design By Geometric Programming

Andrzej M Brandt



Engineering Design By Geometric Programming:

Engineering Design by Geometric Programming Clarence Zener,1971 *Engineering Design Optimized with Geometric Programming* Robert E. D. Woolsey,Colorado School of Mines,Walden University (Minneapolis, Minn.),1992

Geometric programming - an approach to optimizing engineering design Theodore S. Glassman,1968 **A Seminar Research Report on Engineering Design by Geometric Programming** R. H. Barghaus,Joseph G. Ecker,1974*

Conceptual Engineering Design and Optimization Methodologies Using Geometric Programming Berk Öztürk,2018 Geometric programs GPs and other forms of convex optimization have recently experienced a resurgence due to the advent of polynomial time solution algorithms and improvements in computing Observing the need for fast and stable methods for multidisciplinary design optimization MDO previous work has shown that geometric programming can be a powerful framework for MDO by leveraging the mathematical guarantees and speed of convex optimization However there are barriers to the implementation of optimization in design In this work we formalize how the formulation of non linear design problems as GPs facilitates design process Using the principles of pressure and boundedness we demonstrate the intuitive transformation of physics and data based engineering relations into GP compatible constraints by systematically formulating an aircraft design model We motivate the difference of convex GP extension called signomial programs SPs in order to extend the scope and fidelity of the model We detail the features specific to Gpkit an object oriented GP formulation framework which facilitate the modern engineering design process Using both performance and mission modeling paradigms we demonstrate the ability to model and design increasingly complex systems in GP and extract maximal engineering intuition using sensitivities and tradespace exploration methods Though the methods are applied to an aircraft design problem they are general to models with continuous explicit constraints and lower the barriers to implementing optimization in design *Engineering Design and Optimization of Thermofluid Systems* David S. K. Ting,2021-02-17 A practical and accessible introductory textbook that enables engineering students to design and optimize typical thermofluid systems *Engineering Design and Optimization of Thermofluid Systems* is designed to help students and professionals alike understand the design and optimization techniques used to create complex engineering systems that incorporate heat transfer thermodynamics fluid dynamics and mass transfer Designed for thermal systems design courses this comprehensive textbook covers thermofluid theory practical applications and established techniques for improved performance efficiency and economy of thermofluid systems Students gain a solid understanding of best practices for the design of pumps compressors heat exchangers HVAC systems power generation systems and more Covering the material using a pragmatic student friendly approach the text begins by introducing design optimization and engineering economics with emphasis on the importance of engineering optimization in maximizing efficiency and minimizing cost Subsequent chapters review representative thermofluid systems and devices and discuss basic mathematical models for describing thermofluid systems

Moving on to system simulation students work with the classical calculus method the Lagrange multiplier canonical search methods and geometric programming Throughout the text examples and practice problems integrate emerging industry technologies to show students how key concepts are applied in the real world This well balanced textbook Integrates underlying thermofluid principles the fundamentals of engineering design and a variety of optimization methods Covers optimization techniques alongside thermofluid system theory Provides readers best practices to follow on the job when designing thermofluid systems Contains numerous tables figures examples and problem sets Emphasizing optimization techniques more than any other thermofluid system textbook available Engineering Design and Optimization of Thermofluid Systems is the ideal textbook for upper level undergraduate and graduate students and instructors in thermal systems design courses and a valuable reference for professional mechanical engineers and researchers in the field

Geometric Programming for Design Equation Development and Cost/Profit Optimization (with illustrative case study problems and solutions), Third Edition Robert C. Creese, 2022-05-31

Geometric Programming is used for cost minimization profit maximization obtaining cost ratios and the development of generalized design equations for the primal variables The early pioneers of geometric programming Zener Duffin Peterson Beightler Wilde and Phillips played important roles in its development Five new case studies have been added to the third edition There are five major sections 1 Introduction History and Theoretical Fundamentals 2 Cost Minimization Applications with Zero Degrees of Difficulty 3 Profit Maximization Applications with Zero Degrees of Difficulty 4 Applications with Positive Degrees of Difficulty and 5 Summary Future Directions and Geometric Programming Theses Dissertations Titles The various solution techniques presented are the constrained derivative approach condensation of terms approach dimensional analysis approach and transformed dual approach A primary goal of this work is to have readers develop more case studies and new solution techniques to further the application of geometric programming

Geometric Programming for Engineering Design Optimization Guri Singh Brar, 1981 Advances in Geometric Programming Mordecai Avriel, 2013-03-09

In 1961 C Zener then Director of Science at Westinghouse Corporation and a member of the U S National Academy of Sciences who has made important contributions to physics and engineering published a short article in the Proceedings of the National Academy of Sciences entitled A Mathematical Aid in Optimizing Engineering Design In this article Zener considered the problem of finding an optimal engineering design that can often be expressed as the problem of minimizing a numerical cost function termed a generalized polynomial consisting of a sum of terms where each term is a product of a positive constant and the design variables raised to arbitrary powers He observed that if the number of terms exceeds the number of variables by one the optimal values of the design variables can be easily found by solving a set of linear equations Furthermore certain invariances of the relative contribution of each term to the total cost can be deduced The mathematical intricacies in Zener's method soon raised the curiosity of R J Duffin the distinguished mathematician from Carnegie Mellon University who joined forces with Zener in laying the rigorous

mathematical foundations of optimizing generalized polynomials Interestingly the investigation of optimality conditions and properties of the optimal solutions in such problems were carried out by Duffin and Zener with the aid of inequalities rather than the more common approach of the Kuhn Tucker theory Optimum Design of Structures Lahbib Chibani,2012-12-06 This book presents the integrated approach of analysis and optimal design of structures This approach which is more convenient than the so called nested approach has the difficulty of generating a large optimization problem To overcome this problem a methodology of decomposition by multilevel is developed This technique which is also suitable for implementation on parallel processing computers has the advantage of reducing the size of the optimization problem generated The geometric programming for both equality and inequality constraints is used in the optimization , *Geometric Programming for Design and Cost Optimization 2nd edition* Robert Creese,2022-05-31 Geometric programming is used for design and cost optimization the development of generalized design relationships cost ratios for specific problems and profit maximization The early pioneers of the process Zener Duffin Peterson Beightler Wilde and Phillips played important roles in the development of geometric programming There are three major areas 1 Introduction History and Theoretical Fundamentals 2 Applications with Zero Degrees of Difficulty and 3 Applications with Positive Degrees of Difficulty The primal dual relationships are used to illustrate how to determine the primal variables from the dual solution and how to determine additional dual equations when the degrees of difficulty are positive A new technique for determining additional equations for the dual Dimensional Analysis is demonstrated The various solution techniques of the constrained derivative approach the condensation of terms and dimensional analysis are illustrated with example problems The goal of this work is to have readers develop more case studies to further the application of this exciting tool Table of Contents Introduction Brief History of Geometric Programming Theoretical Considerations The Optimal Box Design Case Study Trash Can Case Study The Open Cargo Shipping Box Case Study Metal Casting Cylindrical Riser Case Study Inventory Model Case Study Process Furnace Design Case Study Gas Transmission Pipeline Case Study Profit Maximization Case Study Material Removal Metal Cutting Economics Case Study Journal Bearing Design Case Study Metal Casting Hemispherical Top Cylindrical Side Riser Case Study Liquefied Petroleum Gas LPG Cylinders Case Study Material Removal Metal Cutting Economics with Two Constraints The Open Cargo Shipping Box with Skids Profit Maximization Considering Decreasing Cost Functions of Inventory Policy Summary and Future Directions Thesis and Dissertations on Geometric Programming *Proceedings of the Princeton Symposium on Mathematical Programming* Harold W. Kuhn,2015-03-08 This volume contains thirty three selected general research papers devoted to the theory and application of the mathematics of constrained optimization including linear programming and its extensions to convex programming general nonlinear programming integer programming and programming under uncertainty Originally published in 1971 The Princeton Legacy Library uses the latest print on demand technology to again make available previously out of print books from the distinguished backlist of Princeton University Press

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Computational Mathematical Programming Klaus Schittkowski, 2013-06-29 This book contains the written versions of main lectures presented at the Advanced Study Institute ASI on Computational Mathematical Programming which was held in Bad Windsheim Germany F R from July 23 to August 2 1984 under the sponsorship of NATO The ASI was organized by the Committee on Algorithms COAL of the Mathematical Programming Society Co directors were Karla Hoffmann National Bureau of Standards Washington U S A and Jan Teigen Rabobank Nederland Zeist The Netherlands Ninety participants coming from about 20 different countries attended the ASI and contributed their efforts to achieve a highly interesting and stimulating meeting Since 1947 when the first linear programming technique was developed the importance of optimization models and their mathematical solution methods has steadily increased and now plays a leading role in applied research areas The basic idea of optimization theory is to minimize or maximize a function of several variables subject to certain restrictions This general mathematical concept covers a broad class of possible practical applications arising in mechanical electrical or chemical engineering physics economics medicine biology etc There are both industrial applications e g design of mechanical structures production plans and applications in the natural engineering and social sciences e g chemical equilibrium problems chromatography problems

Operations Research A. M. Natarajan, P. Balasubramani, 2006

Criteria and Methods of Structural Optimization Andrzej M Brandt, 1987-06-30 This book is intended to serve all those who are interested in structural optimization whether they work in this field or study it for other purposes Rapid growth of interest in the cognitive aspects of optimization and the increasing demands that the present day engineer has to meet in modern design have created the need of a monographic treatment of the subject The vast number and wide range of structural optimization problems formulated and investigated in the last twenty years call for an attempt to sum up the present state of knowledge in this domain and to outline the directions of its further development The present authors undertook this task hoping that the result would stimulate further work towards finding new methods and solutions and increasing the range of applications of the optimization methods to structural design The immediate aim of the book is to present the basic criteria and methods of optimization and to provide a reference guide to the most important publications in the field The book consists of fourteen chapters Chapter 1 introduces the basic concepts definitions and assumptions relating to structural optimization Chapter 2 gives the foundations of optimization for minimum elastic strain potential or maximum rigidity and sets a basis for optimization of bar plate and lattice structures Chapter 3 presents criteria of strength design and their applications to plane structures

Engineering Optimization Singiresu S. Rao, 2009-07-20 Technology Engineering Mechanical Helps you move from theory to optimizing engineering systems in almost any industry Now in its Fourth Edition

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Structural Optimization, A. Borkowski, S. Jendo, W. Prager, M. Save, 1990-01-31 *Reliability and Optimization of Structural Systems* P. Thoft-Christensen, 2012-12-06 From the Preface: The Proceedings contain papers presented at the 1st Working Conference on Reliability and Optimization of Structural Systems, Aalborg, Denmark, May 6-8, 1987. The conference was the first scientific meeting of the new IFIP Working Group 7.5 on Reliability and Optimization of Structural Systems. The purpose of the Working Group 7.5 is to promote modern structural system optimization and reliability theory to advance international cooperation in the field of structural system optimization and reliability theory, to stimulate research development and application of structural system optimization and reliability theory, to further the dissemination and exchange of information on reliability and optimization of structural system optimization and reliability theory, to encourage education in structural system optimization and reliability theory.

Nonlinear Programming Mordecai Avriel, 2003-01-01 This overview provides a single-volume treatment of key algorithms and theories. Begins with the derivation of optimality conditions and discussions of convex programming, duality, generalized convexity, and analysis of selected nonlinear programs, and then explores techniques for numerical solutions and unconstrained optimization methods. 1976 edition. Includes 58 figures and 7 tables.

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