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]:

$$\min \quad f_0(x) \tag{1}$$

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

$$g_l(x) = 1, \quad l = 1, 2, \ldots, q, \tag{3}$$

$$x = (x_1, x_2, \ldots, x_n), \tag{4}$$

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

$$g_l(x) = c_l \prod_{i=1}^{m} x_i^{\alpha_{il}} \tag{5}$$

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

$$f_k(x) = \sum_{h=1}^{H_k} c_{hk} \prod_{i=1}^{m} x_i^{\alpha_{ihk}}. \tag{6}$$

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. Sherali 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

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Engineering Design by Geometric Programming Clarence Zener,1971   Geometric Programming for Design Equation Development and Cost/Profit Optimization Robert C. Creese,2016-12-27 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   *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   *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   **A Seminar Research Report on Engineering Design by Geometric Programming** R. H. Barghaus,Joseph G. Ecker,1974*   *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 **Engineering Design** Reuven R. Levary,1988 **Geometric Programming for Engineering Design Optimization** Guri Singh Brar,1981 *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 Professor Singiresu Rao s acclaimed text Engineering Optimization enables readers to quickly master and apply all the important optimization methods in use today across a broad range of industries Covering both the latest and classical optimization methods the text starts off with the basics and then progressively builds to advanced principles and applications This comprehensive text covers nonlinear linear geometric dynamic and stochastic programming techniques as well as more specialized methods such as multiobjective genetic algorithms simulated annealing neural networks particle swarm optimization ant colony optimization and fuzzy optimization Each method is presented in clear straightforward language making even the more sophisticated techniques easy to grasp Moreover the author provides Case examples that show how each method is applied to solve real world problems across a variety of industries Review questions and problems at the end of each chapter to engage readers in applying their newfound skills and knowledge Examples that

demonstrate the use of MATLAB for the solution of different types of practical optimization problems References and bibliography at the end of each chapter for exploring topics in greater depth Answers to Review Questions available on the author s Web site to help readers to test their understanding of the basic concepts With its emphasis on problem solving and applications Engineering Optimization is ideal for upper level undergraduates and graduate students in mechanical civil electrical chemical and aerospace engineering In addition the text helps practicing engineers in almost any industry design improved more efficient systems at less cost **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 *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 These editions preserve the original texts of these important books while presenting them in durable paperback and hardcover editions The goal of the Princeton Legacy Library is to vastly increase access to the rich scholarly heritage found in the thousands of books published by Princeton University Press since its founding in 1905 **Design and Optimization of Thermal Systems, Third Edition** Yogesh Jaluria,2019-09-06 Design and Optimization of Thermal Systems Third Edition with MATLAB Applications provides systematic and efficient approaches to the design of thermal systems which are of interest in a wide range of applications It presents basic concepts and procedures for conceptual design problem formulation modeling simulation design evaluation achieving feasible design and optimization Emphasizing modeling and simulation with experimentation for physical insight and model validation the third edition covers the areas of material selection manufacturability economic aspects sensitivity genetic and gradient search methods

knowledge based design methodology uncertainty and other aspects that arise in practical situations This edition features many new and revised examples and problems from diverse application areas and more extensive coverage of analysis and simulation with MATLAB   *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   *Mechanical Engineers' Handbook, Volume 2* Myer Kutz,2015-02-06 Full coverage of electronics MEMS and instrumentation and control in mechanical engineering This second volume of Mechanical Engineers Handbook covers electronics MEMS and instrumentation and control giving you accessible and in depth access to the topics you ll encounter in the discipline computer aided design product design for manufacturing and assembly design optimization total quality management in mechanical system design reliability in the mechanical design process for sustainability life cycle design design for remanufacturing processes signal processing data acquisition and display systems and much more The book provides a quick guide to specialized areas you may encounter in your work giving you access to the basics of each and pointing you toward trusted resources for further reading if needed The accessible information inside offers discussions examples and analyses of the topics covered rather than the straight data formulas and calculations you ll find in other handbooks Presents the most comprehensive coverage of the entire discipline of Mechanical Engineering anywhere in four interrelated books Offers the option of being purchased as a four book set or as single books Comes in a subscription format through the Wiley Online Library and in electronic and custom formats Engineers at all levels will find Mechanical Engineers Handbook Volume 2 an excellent resource they can turn to for the basics of electronics MEMS and instrumentation and control   **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   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 christollography problems   Design of Thermal Energy Systems Pradip Majumdar,2021-06-01 Design of Thermal Energy Systems Pradip Majumdar Northern Illinois University USA A comprehensive introduction to the design and analysis of thermal energy systems Design of Thermal Energy Systems covers the fundamentals and applications in thermal energy systems and components including conventional power generation and cooling systems renewable energy systems heat recovery systems heat sinks and thermal management Practical examples are used throughout and are drawn from solar energy systems fuel cell and battery thermal management electrical and electronics cooling engine exhaust heat and emissions and manufacturing processes Recent research topics such as steady and unsteady state simulation and optimization methods are also included Key features Provides a comprehensive introduction to the design and analysis of thermal energy systems covering fundamentals and applications Includes a wide range of industrial application problems and worked out example problems Applies thermal analysis techniques to generate design specification and ratings Demonstrates how to design thermal systems and components to meet engineering

specifications Considers alternative options and allows for the estimation of cost and feasibility of thermal systems Accompanied by a website including software for design and analysis a solutions manual and presentation files with PowerPoint slides The book is essential reading for practicing engineers in energy and power industries consulting engineers in mechanical electrical and chemical engineering and senior undergraduate and graduate engineering students

    Advances in Geometric Programming Mordecai Avriel,2013-03-09 In 1961 C Zener then Director of Science at Westinghouse Corpora tion 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 Mathe matical 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 Interes tingly 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   *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 opti mization whether they work in this field or study it for other purposes Rapid growth of interest in the cognitive aspects of optimization and the increas ing 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 pres ent 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

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