

刘 剑 贾进章 郑 丹 / 著



流体网络 FLUID NETWORK THEORY 理论

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FLUID NETWORK THEORY

刘 剑 贾 进 章 郑 丹 著

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内容简介

网络理论是拓扑数学分支之一——图论的重要内容，它是一门既古老而又年轻的学科，其研究可以追溯到 17 世纪的 Euler 与 Königsberg 桥。但是直至科学发展的今天，无论是在该学科的自身研究上，还是它的应用领域都仍在发展之中。网络理论和方法已经广泛地渗透到物理学、生物学、运筹学、信息论、控制论、管理科学和计算机科学等领域，并在工程技术、经济、军事等诸多方面都有着极为广泛的应用。从宏观上讲，现代社会是一个由通讯网络、运输网络、能源和物资分配网络、人才与资本流向网络构成的巨大的复杂系统。从现实生活中，我们日常见到有电路板网络、集中空调网络、城市供水、供气、供热网络、矿井通风网络等等不计其数。而在微观世界，动物的神经网络，脑模型网络，血液循环网络，植物的养分吸取及输送网络等等。在这众多的网络世界中，供水、供气、通风网络，即所谓的流体网络，与其它网络相比既有其广泛的代表性，又不失其自身的复杂性。所以本书以流体网络为对象，结合图论理论的一般性和流体网络的特殊性进行论述。

该书以集合论为指导，首先建立了一整套描述流体网络的符号体系，如节点的关联分支、邻接节点、入度与出度、入边与出边、网络源点与汇点、分支着色、搜索分支的入栈与出栈等等。另外对一些概念重新进行了定义，如重新界定并区分了任意两节点之间路径与通路的概念，当路径的两个端点重合时就是回路，通路的两端点重合时就是单向回路。网络中存在单向回路时，将会导致通路的矩阵算法以及有向图的搜索失效，计算通路数的公式也不适用。而含有单向回路的网络在现实工程实践问题当中是相当普遍的。符号体系的建立和一些概念的界定，不仅使本书的叙述更加简洁，而且为更科学地描述网络的拓扑关系及其算法奠定了基础。

排序与搜索是流体网络非矩阵算法的基础，书中论述了有向图和无向图的深度优先和宽度优先搜索算法，以及利用深度优先搜索法确定网络全部通路的算法。基于搜索技术的树、回路、通路、通路数等算法要比矩阵算法更为有效。此外，书中还通过反例证明了最小树的 Dijkstra 矩阵算法是错误的。

独立通路的概念是本书的一个重要概念，所谓独立通路就是在

找通路的过程中,后面的通路至少要含有一条前面的通路所不含有的分支。独立通路是在“找通路的过程中”所涉及的一个概念,而不是在一个通路集中“每一条通路中都至少含有一条其它通路所不含有的分支”,即独立通路是一种方法,尽管它也有一个对应的通路集。独立通路思想构建了网络极值流、平衡图绘制算法的基础。网络流是图论中的重要内容,本书提出的独立通路法确定网络极值流其复杂度是 $O((n-m+2) \times (m-1))$,比目前公认较优的 Dinic 算法的复杂度 $O(m^2n)$ 降一个数量级。

平衡图是描述流体网络拓扑关系及其各种性质的最科学、直观、定量的表达方法,该书除了系统介绍平衡图的概念及其性质之外,重点论述了绘制平衡图的数学模型及其算法,还提出了柱面网络的平衡图绘制原理。

角联结构是网络中的一种特殊的拓扑关系,它呈现出来的性质也是极其特殊的。角联分支本身具有不稳定性,而角联结构的存在对提高网络的整体稳定性和可靠性却是有利的。一些问题追求尽量避免角联结构的存在,而另一些问题又克求创造角联结构。该书系统提出了确定角联分支及其关联分支的数学模型和算法(角联结构7元组),并论证了为什么应当按无向图来确定角联结构,而不能按有向图的原理。

在网络分流方面,在详细介绍分流算法的基础上,对分流算法的一些具体问题处理和评价进行论述,尤其是算法的收敛性。其中用5次方程拟合流体动力机械特性曲线代替2次方程,是避免算法假收敛的有效手段之一。

人工简化流体网络是一件非常容易的事情,但是由计算机自动进行简化,其算法却是非常复杂的,本书提出的网络简化算法,对网络分析以及提高与网络相关的一些算法的效率具有重要意义。

流体网络的可靠性与一般系统的可靠性相比有其特殊性,主要体现在“系统本身就是网络”,书中系统论述了流体网络分支的灵敏性与网络的可靠性。

该书重点介绍了作者在该领域的研究成果,为了使全书内容具有系统性和完整性,同时也为了适合作高等学校相关本科及硕士专业的教材使用,引用了图论、流体力学和空气动力学的一些内容。该书可作为高等学校安全、环境、采矿、通讯、交通运输、给水、供热、管理等工程领域相关专业的教材或教学参考书。也可作为科研、工程设计和工程管理领域工程技术人员的参考书。

Abstract

Network theory is an important content of graph theory, which is one of the branches of topology. Network theory is as old as well as young discipline and its research can trace back to Euler and Königsberg bridge of century 17. But until today when science is developed, whether the research of the discipline or its application domain is still in development. Network theory and its methods have widely permeated into the domains of physics, biology, operational research, information theory, cybernetics, management science and computer science, etc., which have most extensive applications in the aspects of engineering technique, economy, military affairs and so on. Speaking from macro view, modern society is a huge and complicated system composed of communication network, transportation network, energy resources and material distribution network, talents and capital flow direction network. In actual life, we can find innumerable networks, such as circuit board network, central air-conditioning network, urban water supply, air supply, heat supply network and mine ventilation system. In micro world, moreover, there are neural network of animal, brain model network, blood circulation network, nutrient absorption and transportation network of plant, etc. Among the numerous network world, water supply, air supply and ventilation network, namely so-called fluid network, comparing with other networks, has extensive representation and complexity of itself. In the book, fluid network is considered as the discussing target, combined with the universality of graph theory and the particularity of fluid network, discussion is performed.

Set theory is a guidance of the book, a complete set of symbol system to describe fluid network, such as incident branch of node, adjacent node, in-degree and out-degree, in branch and out branch, source node and sink node of network, branch coloration, push and pop of search branch and so on, are established firstly. In addition, some concepts are redefined. For example, the concept of route and path between any two nodes are redefined and differentiated. If the two endpoints of a route are the same node, the route is a circuit; if the two endpoints of a path are the same node, the path is a unidirectional circuit. When unidirectional circuits exist in a network,

the matrix algorithm for paths and the search in a directed graph will fail, formula for computing path number doesn't fit too. Moreover the network with unidirectional circuits is prevalent in the problem of actual engineering practice. The establishment of symbol system and the definition of some concepts, not only make the narration brief, but also settle foundations for a more scientific description of the topology relation of network and their algorithms.

Sort and search are the basics of non-matrix algorithms for fluid network, depth-first search algorithm and breadth-first search algorithm for directed and non-directed graph and the algorithm for the determination of all paths of network by using depth-first search algorithm are discussed in the book. Search technique based algorithms for tree, circuit, path and path number are more effective than those based on matrix. Furthermore, matrix based Dijkstra algorithm for minimum tree is proved to be wrong through a counter example in the book.

The concept of independent path is one of the important concepts in the book. What is called independent path namely in the process of finding paths, posterior paths at least include one branch not including in anterior paths. Independent paths is a concept referring to "the process of finding paths", rather than in a path set, "every path has at least one branch not including in the other paths", namely independent path is a method, although it also has a corresponding path set. The idea of independent path set up the basics of extremal flow and the plotting of equilibrium diagram. Network flow is one of the important contents of graph theory. The complexity of independent path based determination of extremal flow is $O((n-m+2) \times (m-1))$, which is one order of magnitude less than the complexity of Dinic algorithm, which is considered to be excellent and its complexity is $O(m^2n)$.

Equilibrium diagram is a scientific, directed-viewing and quantitative expression method to describe topology relation of fluid network and its properties. In the book, in addition to the concept of equilibrium diagram and its properties are introduced systematically, the mathematical models of plotting of equilibrium graph and its algorithm are discussed emphatically, the plotting principle of equilibrium diagram of cylinder network is brought forward too.

Diagonal structure is a sort of particular topology relation of network, and its properties are also complicated. Diagonal branch itself has instability, but the existence of diagonal structure is favorable for improving the integral stability and reliability of network. Some problems may try to avoid the existence of diagonal structure, while other problems may try to create diagonal structure. Mathematical model and algorithm (namely seven-element group) for determining diagonal branch and its adjacent branch are advanced systematically

in the book, and why non-directed graph rather than directed graph is used to determine diagonal structure is discussed and proved.

In the aspect of network flow distribution, based on the detailed introduction of algorithms for flow distribution, some specific problems and estimation of algorithms for flow distribution especially the convergence of algorithms are discussed. Quintic equation rather than quadratic equation is used to fit characteristic curves of fluid power machine, which is an efficient means to avoid false convergence of algorithms.

Manual simplification of fluid network is an easy job, but the algorithm for computer-based simplification is very complicated, and the algorithm is put forward in the book, which is significant for network analysis and algorithms relative to network.

Reliability of fluid network has some particularities comparing with reliability of general systems, mainly embody in "system itself is network". Sensitivity of branch and reliability of fluid network are discussed systematically.

The research fruits of author in the domain are introduced emphatically. For the sake of the systematicness and integrality of the book, at the same time considering the need of teaching material for correlative undergraduate course and master speciality of university, some contents on graph theory, hydromechanics and aerodynamics are referred. The book can be used as teaching material and teaching reference book for safety, environment, mining, communication, traffic and transportation, water supply, heat supply and management and so on engineering domain and correlative speciality of university. The book can also be used as reference book for engineers and technicians of scientific research, engineering design and management domain.

自1989年以来,我们先后参加了双鸭山、平顶山、铁法、兖州、西山、沈阳、大同、鸡西矿务局,金川有色金属公司等局矿的17个矿井的有关矿井通风系统评价与优化改造方面的课题研究,这些问题的解决,都涉及到一个通风网络解算问题。目前我们正在承担的在淮南矿业(集团)有限责任公司潘一矿和潘三矿实施的国家“十五”攻关项目《重大工业事故与大城市火灾防范及应急技术研究》专题之一《矿井通风系统安全可靠评价和决策技术研究》,其理论基础也是通风网络问题。图论是研究通风网络的基础,十余年来作者在该领域作了一些探讨性的工作。为了使研究内容更具有普遍性和通用性,我们忽略了具体的矿井通风问题,从流体网络的角度执笔撰写了此书。

考虑到安全工程本科专业的教材建设问题,适当增加了一些流体力学、空气动力学等方面的内容,使其更具有系统性和完整性。全书共分11章,第1章为流体网络的基本概念与拓扑关系;第2章为流体网络图的矩阵表示;第3章为排序与搜索算法;第4章介绍了连通图、最小树、回路和生成树;第5章为最短路与极值流的算法;第6章和第7章分别介绍了管流方程、管流阻力定律及动力;第8章介绍了网络分流的Barczyk法、Cross法;第9章论述了流体网络平衡图的性质与绘制算法;第10章介绍了角联结构与网络简化的数学模型;第11章介绍了网络的灵敏性和可靠性。

本书由刘剑提出写作提纲,其中第1、3、4、5、8、9、10章由刘剑执笔,第6、7、11章由贾进章执笔,第2章及第5章部分内容由郑丹执笔,最后由刘剑统一修改定稿。

感谢李艳昌、刘新两位研究生,他们协助绘制了书中的部分图形。感谢为本书的出版作出了各种贡献的有关矿山

的工程技术人员、辽宁工大资源与环境工程学院安全工程系的各位老师及研究生，感谢煤炭工业出版社的有关人员。

本书在内容体系和风格上作了一些创新的尝试，由于我们学识有限，书中缺点和错误在所难免，欢迎读者批评赐教。

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2002年6月



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主持、参加了国家“六五”、“七五”、“十五”攻关项目、国家自然科学基金项目、辽宁省自然科学基金项目等各类科研课题50余项。其中，1994—1998年间，获辽宁省科技进步二等奖两次，三等奖一次；1999年获国家煤炭工业科技进步推广类二等奖。在《ARCHIVES OF MINING SCIENCES》、《煤炭学报》等国内外著名学术刊物及国际学术会议上发表学术论文60余篇。



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