

2 EIGENWERTPROBLEME

Viele numerische Lösungsansätze von z.B. physikalischen Problemen erfordern die Lösung eines sogenannten Eigenwertproblems. Zu einer Matrix $A \in \mathbb{R}^{n \times n}$ finde man eine Zahl $\lambda \in \mathbb{C}$ und einen Vektor $v \in \mathbb{C}^n$, $v \neq 0$, sodass die *Eigenwertgleichung*

$$Av = \lambda v$$

erfüllt ist. Die Zahl λ heißt *Eigenwert* und der Vektor v *Eigenvektor* zum Eigenwert λ . Betrachten wir nun zunächst einige konkrete Beispiele, die auf ein Eigenwertproblem führen.

Beispiel 2.0.1 (Sturm-Liouville-Problem) Die mathematische Modellierung zur Beschreibung der Überlagerung von Schwingungsvorgängen – wie sie etwa beim Brückenbau durchgeführt wird, um Resonanzen zu vermeiden, die einen Brückeneinsturz verursachen könnten – führt auf das sogenannte Sturm-Liouville Problem: Zu einer bekannten stetigen Funktion $r(x) > 0$, $x \in [0, 1]$, finde man die Zahl λ und die Funktion $u(x)$, die die Differenzialgleichung

$$-u''(x) - \lambda r(x) u(x) = 0, \quad x \in (0, 1) \quad (2.1)$$

mit den Randbedingungen

$$u(0) = u(1) = 0$$

erfüllen. Um die Lösung über ein Diskretisierungsverfahren numerisch anzunähern, betrachten wir Gitterpunkte

$$x_j = jh, \quad j = 0, \dots, n, \quad h = \frac{1}{n}$$

und ersetzen $u''(x_j)$ durch den zweiten zentrierten Differenzenquotienten

$$\frac{u(x_j + h) - 2u(x_j) + u(x_j - h))}{h^2}, \quad j = 1, \dots, n-1.$$

Es ergibt sich so ein System

$$Au - \lambda Ru = 0 \quad (2.2)$$

für die Unbekannten λ und $u_i \approx u(x_i)$, $i = 1, \dots, n-1$, wobei

$$A = \frac{1}{h^2} \begin{pmatrix} 2 & -1 & & & \\ -1 & 2 & -1 & & \\ & \ddots & \ddots & \ddots & \\ & & -1 & 2 & -1 \\ & & & -1 & 2 \end{pmatrix}, \quad R = \begin{pmatrix} r(x_1) & & & 0 \\ & r(x_2) & & \\ & & \ddots & \\ 0 & & & r(x_{n-1}) \end{pmatrix}. \quad (2.3)$$

Mit $R^{1/2} = \text{diag}(\sqrt{r(x_1)}, \dots, \sqrt{r(x_{n-1})})$, $R^{-1/2} = (R^{1/2})^{-1}$, $B := R^{-1/2}AR^{-1/2}$ sowie $v = R^{1/2}u$ erhält man aus (2.2) die transformierte Gleichung

$$Bv = \lambda v,$$

also ein Eigenwertproblem.

Bemerkung 2.0.2 Da R regulär ist, hätte man die Gleichung (2.2) auch von links mit R^{-1} multiplizieren und so das Eigenwertproblem $R^{-1}Au = \lambda u$ erhalten können. Im Gegensatz zur Matrix B ist die Matrix $R^{-1}A$ jedoch nicht symmetrisch.

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Table of Contents Eigenwertprobleme Ihre Numerische Beha

1. Understanding the eBook Eigenwertprobleme Ihre Numerische Beha
 - The Rise of Digital Reading Eigenwertprobleme Ihre Numerische Beha
 - Advantages of eBooks Over Traditional Books
2. Identifying Eigenwertprobleme Ihre Numerische Beha
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Eigenwertprobleme Ihre Numerische Beha
 - User-Friendly Interface
4. Exploring eBook Recommendations from Eigenwertprobleme Ihre Numerische Beha
 - Personalized Recommendations
 - Eigenwertprobleme Ihre Numerische Beha User Reviews and Ratings
 - Eigenwertprobleme Ihre Numerische Beha and Bestseller Lists

5. Accessing Eigenwertprobleme Ihre Numerische Beha Free and Paid eBooks
 - Eigenwertprobleme Ihre Numerische Beha Public Domain eBooks
 - Eigenwertprobleme Ihre Numerische Beha eBook Subscription Services
 - Eigenwertprobleme Ihre Numerische Beha Budget-Friendly Options
6. Navigating Eigenwertprobleme Ihre Numerische Beha eBook Formats
 - ePub, PDF, MOBI, and More
 - Eigenwertprobleme Ihre Numerische Beha Compatibility with Devices
 - Eigenwertprobleme Ihre Numerische Beha Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Eigenwertprobleme Ihre Numerische Beha
 - Highlighting and Note-Taking Eigenwertprobleme Ihre Numerische Beha
 - Interactive Elements Eigenwertprobleme Ihre Numerische Beha
8. Staying Engaged with Eigenwertprobleme Ihre Numerische Beha
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Eigenwertprobleme Ihre Numerische Beha
9. Balancing eBooks and Physical Books Eigenwertprobleme Ihre Numerische Beha
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Eigenwertprobleme Ihre Numerische Beha
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Eigenwertprobleme Ihre Numerische Beha
 - Setting Reading Goals Eigenwertprobleme Ihre Numerische Beha
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Eigenwertprobleme Ihre Numerische Beha
 - Fact-Checking eBook Content of Eigenwertprobleme Ihre Numerische Beha
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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
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