

# A survey on Tensor techniques and applications in machine learning

Yuwang Ji, Qiang Wang\*, Xuan Li, Jie Liu

**Abstract**—This survey gives a comprehensive overview of tensor techniques and applications in machine learning. Tensor represents higher order statistics. Nowadays, many applications based on machine learning algorithms require a large amount of structured high-dimensional input data. As the set of data increases, the complexity of these algorithms increases exponentially with the increase of vector size. Some scientists found that using tensors instead of the original input vectors can effectively solve these high-dimensional problems. This survey introduces the basic knowledge of tensor, including tensor operations, tensor decomposition, some tensor-based algorithms, and some applications of tensor in machine learning and deep learning for those who are interested in learning tensors. The tensor decomposition is highlighted because it can effectively extract structural features of data and many algorithms and applications are based on tensor decomposition. The organizational framework of this paper is as follows. In part one, we introduce some tensor basic operations, including tensor decomposition. In part two, applications of tensor in machine learning and deep learning, including regression, supervised classification, data preprocessing, and unsupervised classification based on low rank tensor approximation algorithms are introduced in detail. Finally, we briefly discuss urgent challenges, opportunities and prospects for tensor.

**Index Terms**—machine learning, tensor decomposition, higher order statistics, data preprocessing, classification.

## I. INTRODUCTION

“Tensor” was first introduced by William Ron Hamilton in 1846 and later became known to scientists through the publication of Levi-Civita’s book *The Absolute Differential Calculus* [72]. Because of its structured representation of data format and ability to reduce the complexity of multidimensional arrays, tensor has been gradually applied in various fields, such as Dictionary Learning (Molssen Ghassemi, 2017) [88], Magnetic Resonance Imaging(MRI) (Xiaowen Xu, 2018) [148], Spectral data classification (Konstantinos Makantasis, 2018) [99], and Image deblurring (LeiLei Geng, 2018) [75].

When traditional vector value data is extended to tensor value data, traditional vector value based algorithms will no longer work. Thereupon, some scientists extend the traditional vector-based machine learning algorithms to tensors, such as Support tensor machine(STM) (Tao et al., 2005 [27]; Biswas

and Milanfar, 2017 [121]; Hao et al, 2013 [164]), tensor fisher discriminant analysis (Lechuga, 2015) [38], tensor regression (Hou, 2017) [89], tensor completion (Y. Du, 2019) [150], and so on. Recently, a series of new algorithms based on tensor have been widely used in biomedicine and image processing. Compared with traditional vector-based algorithms, tensor-based algorithms can achieve lower computational complexity and better accuracy. Through these tensor-based algorithms, high-dimensional problems can be solved effectively, and accuracy can be improved without destroying the data structure.

The key references for this survey are (A. Cichocki, 2017) [3] and (T. G. Kolda, 2009) [127]. The main purpose of this survey is to introduce basic machine learning applications related to tensor decomposition and tensor network model. Similar to matrix decomposition, tensor decomposition is used to decompose complex high-dimensional tensor into the form of the sum of products of factor tensor or factor vector. Tensor network decomposes the high-dimensional tensor into sparse factor matrices and low-order core tensor, which we call factors or blocks. In this way, we set the compression (that is, distributed) representation of large-size data, enhancing the advantage of interpretation and calculation.

Tensor decomposition is regarded as a sub-tensor network in this survey. That is to say, the decomposition of tensor can be used in the same way as the tensor network. We can divide the data into related and irrelevant parts by using tensor decomposition. High-dimensional big data can be compressed several times without breaking data correlation by using tensor decomposition (tensor network). Moreover, tensor decomposition can be used to reduce unknown parameters, and then the exact solution can be obtained by alternate iterative algorithms.

We provide a general block diagram of the survey (see figure 1). The survey consists of two parts. In part one, we first give the basic definition and notations of tensor in Chapter A. Then we introduce the basic operation of tensor, and the block diagram of the network structure of tensor in Chapter B. Next, we begin to describe tensor decomposition, including several famous decompositions such as the CP (regularization) decomposition, the Tucker decomposition, the Tensor train decomposition and Higher-order singular value decomposition (also known as higher-order tensor decomposition) in Chapter C. In Chapter D, we give a detailed description of tensor train decomposition and the related algorithms. In Chapter E, i.e., the last section of the first part, we summarize the advantages and disadvantages of these decompositions and applications. In part two, we mainly describe tensor application algorithms in machine learning and deep learning. In Chapter A, we introduce the application of structured tensor in data preprocessing

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## **Table of Contents Tensor Techniques In Physics Learning Development Institute**

1. Understanding the eBook Tensor Techniques In Physics Learning Development Institute
  - The Rise of Digital Reading Tensor Techniques In Physics Learning Development Institute
  - Advantages of eBooks Over Traditional Books
2. Identifying Tensor Techniques In Physics Learning Development Institute
  - 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 Tensor Techniques In Physics Learning Development Institute
  - User-Friendly Interface
4. Exploring eBook Recommendations from Tensor Techniques In Physics Learning Development Institute
  - Personalized Recommendations
  - Tensor Techniques In Physics Learning Development Institute User Reviews and Ratings
  - Tensor Techniques In Physics Learning Development Institute and Bestseller Lists
5. Accessing Tensor Techniques In Physics Learning Development Institute Free and Paid eBooks

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