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Summary of Dissertation

Dissertation title

Multi-Scale Topological Intelligence for

Spatiotemporal Data Analysis

(時空間データ解析のためのマルチスケール

トポロジカルインテリジェンス)

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(Signature)

(Summary of dissertation)

In recent years, with the rapid development of Society 5.0, digital twins, and cyber-physical systems, various types of intelligent methodologies have been applied to big data analysis. The intelligent methodology using the topological features and structures hidden in big data for search, prediction, clustering, classification, and learning, is called topological intelligence. For example, the topological mapping is often applied to extract topological features and structures from spatiotemporal data such as image data and point cloud data measured from sensors. Growing neural gas (GNG) has been proposed to extract topological features and to conduct clustering simultaneously. However, as the resolution of data or sensors increases, the current GNG methods cannot process it efficiently in real time from the viewpoint of computational cost, and the topological maps cannot provide different levels of details as required by humans and robots.

Therefore, this thesis proposes the concept of multi-scale topological intelligence to improve the efficiency and effectiveness of spatiotemporal data analysis in real time. The multi-scale process can be applied to both the input part and the output part, where the input part considers data sampling, and the output part considers abstract or detailed information. Therefore, this study proposes two novel GNG methods, namely, multi-scale distributed batch learning GNG (MS-DBL-GNG) and top-down multi-layer GNG (TD-ML-GNG). MS-DBL-GNG improves the extraction speed and stability problems of previous GNG methods. TD-ML-GNG solves the problem of abstract and detailed hierarchical learning. Next, the proposed methods are applied to multi-camera calibration. The obtained results show that the proposed method can shorten the matching time in multi-camera calibration by more than half, and can reduce the noise in the point cloud and improve the matching success rate. Secondly, the topological map is applied as a short-term memory in the person recognition system. The obtained results show that the proposed method can improves the recognition results and enables continuous recognition in various distance conditions.

This thesis is organized as follows. Chapter 1 explains the social background leading to this thesis research objectives. The aim and main contribution of the research are also discussed and highlighted in this chapter.

Note: Summary should be in approximately 1,000 words.

For a dissertation whose title is in English, provide a Japanese translation in parentheses "()."

(Summary of dissertation)

Chapter 2 explains the related works, literature reviews, and justifications relevant to this thesis. First, this chapter introduces the topological intelligence and multi-scale approaches. Furthermore, two main mapping approaches using static topological structure and dynamic topological structure in the topological mapping methods. Next, this chapter explains the methodology of GNG and its related works, and discusses the advantage and disadvantage of each method. Finally, the applicability of GNG and the social application of topological intelligence is discussed from the viewpoint of big data analysis in real time.

In Chapter 3, a novel multi-scale distributed batch learning GNG (MS-DBL-GNG) is proposed to reduce the computational time for topological mapping, and to improve the learning stability. Basically, there is a trade-off between the computational cost and learning performance. Especially, it is difficult for GNG to obtain good topological structure in case of quick learning. Therefore, a novel edge cutting method is introduced as a post-processing of GNG to remove those unimportant edges from the network. Numerical comparison results based on benchmark tests show that the proposed method can obtain the similar clustering results with less computational time, and outperforms the several well-known clustering methods and previous GNG methods.

Chapter 4 discusses the applicability of static predefined topological structure in spatial data analysis and gives an example of multi-camera calibration using the extracted topological maps. To enhance the extraction performance in the topological mapping from point cloud data, a biologically inspired multi-scale process is implemented in MS-DBL-GNG. In the numerical experiments, two different types of complex environment views are used to demonstrate that multi-camera calibration can be automatically performed using static topological maps. The topological structure is used for the local matching by random sample consensus. Finally, these two different topological maps are integrated into one global map to reduce the mismatched topological features of multi-camera. The effectiveness of the proposed method is discussed through numerical experiments using several views from different camera positions.

In Chapter 5, a novel top-down multi-layer GNG (TD-ML-GNG) is proposed to provide multi-level topological maps with different granularity as a hierarchical clustering method. It first defines the details of the top layer, then uses it to form the lower layer step by step. In the hierarchical learning, input is fed into the top layer and then selected sub-nodes in the lower layer are learned. At the same time, the parent node also learns these changes and updates accordingly. Through the hierarchical learning, multiple topological graphs can be formed simultaneously. The effectiveness of the proposed method is discussed through benchmark tests.

Chapter 6 discusses the applicability of dynamic topological structures in temporal data analysis and gives an example of short-term memory system in a person recognition system. Through this short-term memory system, continuous recognition at different distances can be achieved. Person recognition is first divided into face recognition and body recognition, and then the Takagi-Sugeno-Kang fuzzy model is used to integrate these recognition results. If the recognition is accepted, the extracted features are pushed to the GNG short-term memory system for subsequent recognition. Several experimental results support the effectiveness of the proposed method in the person recognition system.

Concluding remarks are summarized in Chapter 7. Finally, several future research directions in interdisciplinary studies of topological data retrieval are discussed.