

# Chapter 9

## Fuzzy Clustering for Classification of Metamaterial Properties

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### ABSTRACT

*Metamaterials are a class of artificially engineered materials that exhibit unique physical and electromagnetic properties not found in natural materials. Fuzzy clustering is a machine learning technique that can be used to classify metamaterials based on their physical and electromagnetic characteristics. In this chapter, the authors provide an overview of metamaterial properties and classification challenges and introduce the basics of fuzzy clustering and its application in material classification. They then present a proposed approach for metamaterial classification using fuzzy clustering, along with case studies demonstrating the effectiveness of this approach. They discuss the potential applications of metamaterial classification and how it can support the development of new metamaterial applications. This chapter provides a valuable resource for researchers and students interested in using fuzzy clustering to classify metamaterials based on their physical and electromagnetic properties.*

### INTRODUCTION

Fuzzy mathematics, fuzzy logic, and fuzzy sets are all related concepts that are used in various fields, including engineering, computer science, and mathematics.

Fuzzy mathematics is a branch of mathematics that deals with uncertainty and vagueness in data. It is an extension of classical set theory that allows for membership in a set to be expressed as a degree of membership rather than a binary true or false

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value (Zadeh, 1965). This allows for more nuanced and flexible representations of complex data sets, making it a useful tool for modelling complex systems.

Fuzzy sets are a type of set in which the membership of an element is represented by a degree of membership rather than a binary true or false value (Zadeh, 1965). Fuzzy sets can be used to represent imprecise or uncertain information in a more nuanced and flexible way than classical sets. They are commonly used in decision-making processes, expert systems, and pattern recognition applications.

In the fields of data analysis including pattern recognition, fuzzy clustering is a method that may be utilised to organise related data points into clusters. In contrast to traditional clustering approaches, fuzzy clustering provides a degree of membership to every data point for each cluster. This degree of membership reflects the uncertainty or fuzziness within the data (Bezdek, 1981). Traditional clustering methods assign every data point to a single cluster. This makes fuzzy clustering well-suited for classifying metamaterial properties based on their physical and electromagnetic characteristics, which may exhibit some degree of ambiguity or overlap.

In the framework of metamaterials, which fuzzy clustering is a technique that may be utilised to assist in the classification of the various classes of metamaterials on the basis of the functions they perform and the applications to which they may be put. For example, a particular metamaterial may have unique electromagnetic properties that make it well-suited for a specific application, such as cloaking or sensing. By using fuzzy clustering to group metamaterials based on their physical and electromagnetic characteristics, researchers can gain insights into the different functional properties of different types of metamaterials, and potentially discover new applications for these materials.

Here, fuzzy clustering is a useful tool for analysing and classifying complex data sets, and can provide valuable insights into the properties and potential applications of metamaterials.

The term “metamaterial” refers to man-made materials that have been developed to have features that cannot be found in materials that occur in nature. These types of materials are designed to arranging microscopic structures in a specific pattern to produce desired physical, electromagnetic, or acoustic properties (Smith et al., 2004). Metamaterials are characterized by their ability to manipulate waves, including light, sound, and electromagnetic radiation, in ways that are not possible with conventional materials.

The use of metamaterials has a vast number of possible applications, ranging from the improvement of imaging technology to the production of cloaks that make people invisible. For example, by manipulating the way that light waves interact with a metamaterial, it is possible to create lenses with significantly improved resolution and to create devices that can detect the smallest amount of light (Yang et al., 2016). In other applications, metamaterials can be used to shield objects from

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