Application of gray system theory in routing protocols for wireless sensor networks

灰色系统理论在无线传感器网络路由协议中的应用

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Abstract. Wireless sensor network routing protocols provide possibilities for the application of gray system theory. This paper introduces the concepts related to gray system theory, analyzes the characteristics of wireless sensor network routing protocols, studies the application of gray correlation analysis, gray prediction analysis and gray clustering analysis to wireless sensor network routing protocols, and provides ideas for future research.

无线传感器网络的路由协议为灰色系统理论的应用提供了可能性。灰色系统理论的应用。本文介绍了灰色系统理论的相关概念，分析了无线传感器网络路由协议的特点，研究了灰色关联分析、灰色预测分析和灰色聚类分析在无线传感器网络路由协议中的应用。预测分析和灰色聚类分析在无线传感器网络路由协议中的应用，并为今后的研究提供思路。

Keywords: Wireless sensor networks, routing protocols, gray system theory.

1 Introduction

Wireless sensor networks (WSNs) are distributed self-organizing networks that consist of multiple sensor nodes that communicate wirelessly with each other. WSNs achieve monitoring and management of the coverage area through mutual collaboration among sensor nodes. Sensor nodes generally consist of common nodes and sink nodes. The common node senses changes in the environment of its coverage area in real time, and then passes the sensed information to the sink node in a single-hop or multi-hop manner. The sink node continuously receives information from the common nodes, judges the overall state of the network and makes corresponding processing by analyzing and fusing the information. Finally, the sink node sends the fused data to the network owner.

Wireless sensor network routing technology is one of the key technologies of WSNs, which completes the task of transmitting data from ordinary nodes to sink nodes and is related to the success of network design. Wireless sensor networks are characterized by a large number of nodes and limited resources, and these characteristics lead to the fact that traditional routing protocols cannot be directly applied to WSNs. Therefore, the study of routing protocols for WSNs has become a key element in this field, and experts at home and abroad have successively proposed various mathematical methods. Researchers proposed the idea of introducing gray system theory into the study of wireless sensor networks, based on the characteristics of space-time correlation of sensory data of sensors in wireless sensor networks, and the

无线传感器网络（WSN）是由多个传感器节点组成的分布式自组织网络，这些节点相互之间进行无线通信。WSNs通过传感器节点之间的相互协作实现对覆盖区域的监测和管理。传感器节点一般由公共节点和汇点组成。节点。公共节点实时感知其覆盖区域内的环境变化。实时感知其覆盖区域的环境变化，然后以单跳或多跳的方式将感知到的信息传递给汇点节点。多跳的方式传递给水汇节点。水汇节点不断接收来自公共节点的信息，判断网络的整体状态，并通过分析和融合信息做出相应处理。最后，水汇节点将融合后的数据发送到融合后的数据发送给网络所有者。无线传感器网络路由技术是WSN的关键技术之一。WSNs的关键技术之一，它完成了从普通节点到汇点的数据传输任务。节点，并与网络设计的成功有关。无线传感器网络的特点是的特点是节点数量多，资源有限，这些特点导致了传统的路由协议不能直接应用于WSNs。因此，WSNs的路由协议的研究已经成为该领域的一个关键因素国内外专家相继提出了各种数学方法。研究人员提出了将灰色系统理论引入到无线传感器网络的研究中。根据无线传感器网络中传感器感觉数据的时空相关性，以及无线传感器网络特有的样本数据小、信息量小的特点，研究人员提出了将灰色系统理论引入无线传感器网络的研究。网络特有的样本数据小、信息量少的特点。

characteristics of small sample data and poor information unique to wireless sensor networks.

This paper investigates the gray system theory and its application to the routing protocols of wireless sensor networks. Chapter 2 introduces the related concepts of gray system theory. Chapter 3 analyses the characteristics of wireless sensor network routing protocols as well as their challenges, and researches the possibility of applying gray system theory to WSNs routing protocols. Chapter 4 studies the existing applications of gray system theory in WSNs routing protocols. Chapter 5 summarizes the analysis of these applications. Finally, we present an outlook on more possible aspects of the application of gray system theory to WSNs routing protocols.

本文研究了灰色系统理论及其在无线传感器网络路由中的应用。协议的应用。第二章介绍了灰色系统理论的相关概念。灰色系统理论。第3章分析了无线传感器网络的特点及其挑战。路由协议的特点及其挑战，并研究了将灰色系统理论应用于WSNs路由协议的可能性。第四章研究了现有的灰色系统理论在WSNs路由协议中的应用。第5章总结了对这些应用的分析。最后，我们对灰色系统理论应用的更多可能进行了展望。灰色系统理论在WSNs路由协议中的应用。

2 Gray System Theory

2.1 Overview of gray system theory

Since the 1960s, with the gradual deepening of people's understanding of uncertain systems, a variety of theoretical research and methodological analysis for uncertain systems have emerged internationally, such as the fuzzy mathematical theory created by Professor Zadeh in the 1960s and the rough set theory created by Pawlak in the 1980s, etc. The gray system theory was born in this environment.

Gray system theory was proposed in 1982 by Prof. Ju-Long Deng, which aims to study uncertainty systems with small data and poor information characteristics. The theory focuses on mining the known information inside the system and setting different models according to different application scenarios. It obtains a correct description of the operation law and development direction of the system [1], by quantifying the intrinsic relationships of the system. The concept of "gray" originates from cybernetics, which is different from "white", where information is known, and "black", where information is unknown. It refers to the system where the information is partly known and partly unknown. Its research contents include gray correlation analysis, gray clustering analysis, gray prediction and gray target decision, etc. The theory plays an important role in system diagnosis and analysis, system element and object classification, system prediction and solution evaluation, and is widely used in various fields of natural disciplines, social disciplines and engineering technology. This chapter introduces gray correlation analysis, gray clustering analysis and gray prediction.

20世纪60年代以来，随着人们对不确定系统认识的逐步加深系统的认识逐渐加深，国际上出现了各种针对不确定系统的理论研究和方法分析。国际上出现了多种不确定系统的理论研究和方法分析，如Zadeh教授在20世纪60年代创立的模糊数学理论和Passet理论。扎德教授在20世纪60年代创立的模糊数学理论和帕夫拉克在80年代创立的粗糙集理论等。20世纪80年代，等等。灰色系统理论就是在这种环境下诞生的。灰色系统理论是由邓聚龙教授在1982年提出的，其目的在于灰色系统理论由邓聚龙教授于1982年提出，旨在研究数据量小、信息特征差的不确定性系统。该理论该理论着重于挖掘系统内部的已知信息，并根据不同的应用场景设置不同的模型。它通过量化系统的内在关系，获得对系统运行规律和发展方向的正确描述[1]。系统的内在关系。灰色 "的概念源于控制论，它不同于信息已知的 "白色 "和 "黑色"。信息是未知的。它指的是系统中的信息部分是灰色关联分析是指信息部分已知、部分未知的系统。其研究内容包括灰色关联分析。灰色聚类分析、灰色预测和灰色目标决策等。该理论在系统诊断和分析、系统元素和对象分类、系统预测和解决方案评估等方面发挥着重要作用。在系统诊断与分析、系统元素与对象分类、系统预测与方案评价等方面发挥着重要作用，并被广泛应用于自然学科、社会学科等各个领域。广泛应用于自然学科、社会学科和工程技术的各个领域。本章介绍了灰色关联分析、灰色聚类分析和灰色预测。

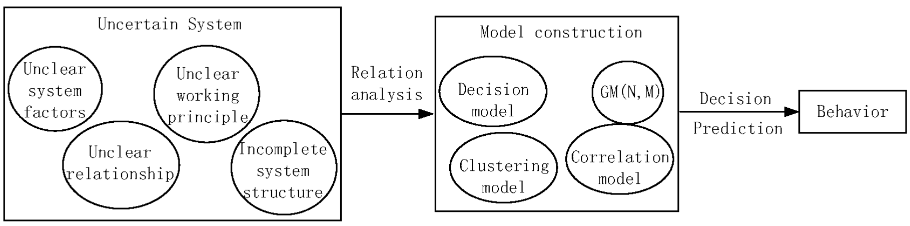

Fig. 1. Principle diagram of gray system theory

2.2 Gray correlation analysis

Gray correlation analysis is a relatively active branch of gray system theory, whose basic idea is to transform the original irregular data of each factor with macroscopic or microscopic proximity to each other into a sequence with a certain development pattern, and then judge the degree of correlation between the sequences according to the geometric similarity of their development curves [1]. The process of gray correlation analysis is:

(1) Select a sequence of attributes that reflect the behavioral characteristics of the system, i.e., gray correlation factors.

(2) Obtain the data of the correlation factors and, if needed, plot the line graph corresponding to each sequence.

(3) The data will be transformed into dimensionless data by the action of the gray correlation operator if the magnitudes of the factors are different.

(4) Calculate the required correlation degree using the gray correlation model.

There are various models for calculating the correlation degree. Early ones include Dunn's gray correlation analysis model based on point correlation coefficient, gray correlation analysis model based on similarity of proximity measure, etc. Later models include absolute correlation, relative correlation and comprehensive correlation analysis models based on overall or global perspective, correlation analysis models based on similarity and proximity perspective, respectively, and so on. As the research advances, the objects of the models are also expanded from the relationship of curves to the analysis of the relationship between surfaces, three-dimensional space and even n-dimensional space hypersurfaces.

Gray correlation analysis makes up for the shortcomings of the classical methods of systematic analysis using mathematical statistics such as regression analysis and principal component analysis when facing small sample data and uncertain data. It is very convenient because there is no requirement for the amount of sample size and whether the sample has obvious patterns.

灰色关联分析是灰色系统理论中比较活跃的一个分支，其基本思想是将各因子的原始不规则数据以宏观的方式进行转换。其基本思想是将各因子的原始不规则数据以宏观或微观上的接近程度转化为具有一定发展的序列。或微观上相互接近的原始不规则数据转化为具有一定发展规律的序列的序列，然后根据各序列发展的几何相似性来判断各序列之间的相关程度。根据其发展曲线的几何相似性判断序列之间的相关程度[1]。灰色关联分析的过程是。(1)选择一个反映系统行为特征的属性序列，即灰色关联分析。系统的属性序列，即灰色关联因子。(2)获得相关因素的数据，如果需要，绘制每个序列对应的线图。(3) 在灰色相关算子的作用下，数据将被转化为无尺寸数据。如果因子的大小不同，数据将被转化为无量纲数据。(4) 使用灰色相关模型计算所需的相关度。有各种计算相关度的模型。早期的包括基于点相关系数的Dunn灰度相关分析模型，基于相似性的灰度相关分析模型。基于近似度量的灰色关联分析模型，等等。后来的模型包括绝对相关、相对相关和综合相关分析模型，基于整体或全局视角的相关分析模型后期模型包括基于整体或全局视角的绝对相关、相对相关和综合相关分析模型，分别基于相似性和接近性视角的相关分析模型，等等。随着研究的深入，模型的对象也从曲线的关系扩展到曲线的关系，扩展到分析曲面、三维空间、甚至九维空间超文本的关系。甚至是n维空间的超曲面。灰色关联分析弥补了经典方法的缺陷使用数学统计的系统分析方法，如回归分析和主成分分析，弥补了其不足。在面对小样本数据和不确定数据时，灰色关联分析弥补了使用数学统计的经典系统分析方法的缺陷，如回归分析和主成分分析。它是它非常方便，因为对样本量和样本是否有明显的模式没有要求。么有明显的模式。

2.3 Gray clustering analysis

Gray cluster analysis is an analysis method that divides the clustered objects or indicators into several clusters based on the gray correlation matrix or the possibility function. According to the clustering object, gray clustering is divided into gray correlation clustering and gray clustering based on the possibility degree function.

Gray correlation clustering analysis is used for the classification of attributes. Its basic idea is to calculate the absolute correlation between attributes based on the data of different observed objects under all attributes to get an upper triangular correlation matrix; then the attributes with correlation greater than eighty percent in the gray correlation matrix are classified into the same gray class, so as to achieve the goal of reducing the attributes to peacekeeping to reduce unnecessary data analysis.

The basic idea of gray clustering analysis based on possibility function is to classify the objects into different gray classes by establishing the possibility function based

灰色聚类分析是一种基于灰色相关矩阵或可能性的分析方法，将聚类对象或指标划分为若干个聚类。函数。根据聚类对象的不同，灰色聚类又分为灰色关联聚类和基于可能性度函数的灰色聚类。灰色关联聚类分析用于属性的分类。其它的基本思想是根据所有属性下的不同观察对象的数据，计算出属性之间的绝对相关度得到一个上三角的相关矩阵；然后，将相关度高的属性归入上三角矩阵。矩阵；然后将灰色相关矩阵中相关度大于百分之八十的属性相关矩阵中相关性大于百分之八十的属性被归入同一灰类，从而达到减少属性的维持，以减少不必要的数据分析。基于可能性函数的灰色聚类分析的基本思路是根据对象关于属性的观测值建立可能性函数，将对象划分为不同的灰色类。灰色聚类分析的基本步骤基于可能性函数的灰色聚类分析的基本步骤是。

on the observed values of the objects about the attributes. The basic steps of gray clustering analysis based on the possibility function are:

(1) Set the possibility function for each indicator to be classified into each subclass respectively.

(2) Determine the clustering weights of each indicator.

(3) Calculate the gray clustering coefficients based on the possibility function of the indicators, the clustering weights, and the observed values of the objects on the indicators.

(4) Count the clustering coefficients of the objects categorized into different gray classes, and determine the objects categorized into the gray class with the largest coefficient.

Possibility function is a mapping function whose value domain is between (0, 1), describing the possible degree of classification of an object into a certain gray class, based on a certain indicator. The possibility function is divided into the upper measure of the possibility function, the triangular possibility function and the lower limit measure of the possibility function. In addition, whether to predetermine the clustering weights of indicators can be decided according to the meaning and scale of indicators, thus forming two types of clustering methods, namely gray variable weight clustering analysis and gray fixed weight clustering analysis.

(1)为每个指标设置可能性函数，将其归入各子类分别。(2) 确定各指标的聚类权重。(3)根据指标的可能性函数、聚类权重、以及观察到的指标值，计算灰色聚类系数，并在此基础上计算出灰色聚类系数。指标的可能性函数、聚类权重以及对象在指标上的观测值，计算灰色聚类系数。指标的观察值。(4) 计算被归入不同灰度等级的对象的聚类系数，确定被归入不同灰度等级的对象。类的对象的聚类系数，并确定归入系数最大的灰类的对象。可能性函数是一个映射函数，其值域在（0，1）之间。描述一个物体被归入某个灰度等级的可能程度。基于某个指标。可能性函数分为可能性函数的上限度量、三角形可能性函数和下限度量可能性函数的测量。另外，是否预先确定指标的聚类权重，可以根据指标的含义和规模来决定，从而形成两种聚类方法，即灰色变权聚类分析和灰色定权聚类分析

2.4 Gray prediction analysis

Gray prediction theory grasps the inner law of gray system by processing the original data of gray system and establishing the gray prediction model, and finally predicts the future state of gray system. The basic steps of gray prediction analysis are.

(1) Accumulate or subtract the original data series with space-time correlation in the gray system, and transform them into data series with regularity.

(2) Establish the corresponding gray differential equations to obtain the data variation patterns.

(3) Use the obtained variation laws to make scientific and fuzzy predictions on the development of the system.

The GM series models are the basic models of gray prediction models, of which the GM(1,1) is one of the typical models. The model that takes the solution of the primal form of the GM(1,1) model as the time response equation is called the GM(1,1) primal difference model.

With the continuous research, a variety of methods emerged for the sequential form and solution form of the GM(1,1) model. Correspondingly, multiple forms of GM(1,1) models have been formed and continuously expanded into GM(1,N) models and GM(N,N) models. In consideration of the fact that gray prediction models perform less well in periodic changes and abrupt changes in data series, researchers have combined gray prediction models with other mathematical models to form combinations of gray periodic extrapolation models, gray time-series models, gray artificial intelligence models, gray Markov models and gray linear regression models, which are applied to different scenarios.

灰色预测理论通过对灰色系统的原始数据进行处理，掌握灰色系统的内在规律，建立灰色预测模型，最终对灰色系统进行预测。灰色系统的原始数据，建立灰色预测模型，最终预测灰色系统的未来状态。灰色系统的未来状态。灰色预测分析的基本步骤是。(1)累积或减去灰色系统中具有时空相关性的原始数据序列。灰色系统中具有时空相关性的原始数据序列，并将其转化为具有规律性的数据序列。(2)建立相应的灰色微分方程，得到数据的变化规律。(3）利用得到的变化规律，对系统的发展进行科学、模糊的预测。系统的发展。GM系列模型是灰色预测模型的基本模型，其中GM(1,1)是其中的一个典型模型。该模型以GM(1,1)的解为基础。GM(1,1)模型的原始形式作为时间响应方程的模型被称为GM(1,1)原始差分模型。随着研究的不断深入，出现了多种方法，用于GM(1,1)模型的序贯形式和求解形式。的形式和求解形式。相应地，多种形式的GM(1,1)模型的多种形式已经形成并不断扩展为GM(1,N)模型和GM(N,N)模型。考虑到灰色预测模型在数据序列的周期性变化和突发性变化中表现较差，研究人员将灰色预测模型与其他数学模型结合起来。灰色预测模型与其他数学模型相结合，形成了灰色周期性推断模型、灰色时间序列模型、灰色人工灰色人工智能模型、灰色马尔科夫模型和灰色线性回归模型，这些模型被应用于不同的场景。被应用到不同的场景中。

3 Challenges of routing protocols for WSNs

WSNs的路由协议的挑战

3.1 Characteristics of routing protocols for WSNs

Wireless sensor networks are different from traditional wireless networks such as wireless LANs and Ad Hoc networks in that their sensor nodes are generally battery-powered and not easily replaceable. Therefore, the energy consumption of the network is the primary concern of the routing protocol design. At the same time, routing protocols should take into account the balanced use of energy of the whole network to achieve efficient information transmission [2].

Wireless sensor networks are often distributed in special environments such as forests and underwater, and the network channels are vulnerable to threats from the environment as well as malicious objects, such as electromagnetic interference, data loss, data tampering, etc., which may result in serious consequences. Therefore, the design of routing protocols should consider security factors, and should also design the corresponding solutions when subjected to security attacks.

During the operation of wireless sensor networks, the number of nodes may decrease due to the failure of nodes [3]; new nodes may also be added according to the actual need to expand the monitoring range. Therefore, routing protocols should quickly make adjustments when the network size changes to ensure that the performance of the network is not affected.

Wireless sensor networks have strong applicability, and in applications with certain requirements for quality of service, the design of routing protocols should consider the quality of service of links such as delay and packet loss rate, in order to ensure the effectiveness of services.

WSNs的路由协议的特点无线传感器网络不同于传统的无线网络，如无线局域网和Ad Hoc网络不同，它们的传感器节点一般都是电池供电的，不容易更换。因此，网络的能量消耗是路由协议设计的首要问题。同时，路由协议应考虑到整个网络能量的平衡使用，以实现高效的信息传输。实现高效的信息传输[2]。无线传感器网络往往分布在森林、水下等特殊环境中，网络通道容易受到来自环境以及恶意物体的威胁，如电磁干扰、数据丢失。数据篡改等，这可能导致严重的后果。因此，在设计路由协议的设计应考虑安全因素，并应在受到安全攻击时设计相应的解决方案。在无线传感器网络的运行过程中，节点的数量可能会因为节点的故障而减少[3]；也可能会根据实际需要增加新的节点来扩大监测范围。新的节点，以扩大监测范围的实际需要。因此，路由协议应该在网络规模发生变化时迅速做出调整，以确保网络的性能不受影响。无线传感器网络具有很强的适用性，在有一定的对服务质量的要求，路由协议的设计应考虑到链路的服务质量，如延迟和丢包率，以保证服务的有效性。

3.2 Challenges of routing protocols for WSNs

Wireless sensor network routing protocols are currently a focus of research in the field of WSNs, and as the research continues, the routing protocols face some challenges as follows:

(1) Metrics balancing

The power supply situation of nodes in wireless sensor networks leads to the energy consumption problem is the primary problem of routing protocol research, and many studies for routing protocols aim to reduce the energy consumption of the network and extend the life cycle of the network. However, wireless sensor networks are complex, in which the performances of the network are not only determined by energy consumption, so that the reasonableness of other network performances should be ensured while considering the reduction of energy consumption. For example, in order to avoid the problem of excessive energy consumption caused by the long-term transmission between nodes, some people adopt the measure of multi-hop transmission between nodes, yet this approach increases the delay of the network while reducing the energy consumption. Therefore, the design of routing protocols for wireless sensor networks faces the challenge of balancing the network metrics so that each performance of the network plays its role appropriately.

WSN的路由协议的挑战无线传感器网络的路由协议是目前WSN领域的研究重点。随着研究的继续，路由协议面临以下一些挑战。(1) 度量的平衡无线传感器网络中节点的供电情况导致的能量消耗问题是路由协议研究的首要问题，很多路由协议的研究都是为了解决这个问题。许多关于路由协议的研究旨在减少网络的能量消耗，延长网络的生命周期。然而，无线传感器网络是复杂的。复杂，网络的性能不仅仅是由能耗决定的，因此在考虑降低能耗的同时，还应该保证其他网络性能的合理性。因此，在考虑减少能源消耗的同时，应确保其他网络性能的合理性。例如，为了避免长期在节点间传输造成的能量消耗过大的问题，有人采用了例如，为了避免节点之间长期传输造成的能量消耗过大的问题，有些人采取了节点之间多跳传输的措施，然而这种方法在减少能量消耗的同时也增加了网络的延迟。因此，无线传感器网络的路由协议的设计面临着如何平衡传感器网络的路由协议设计面临着平衡网络指标的挑战，以便使网络的每个性能都能适当地发挥作用。网络的性能适当地发挥其作用

(2) Stability

The nodes of wireless sensor networks are at rest thus the topology of the network generally does not change [4]. However, sensor nodes can be affected by their own and environmental factors to fail, or need to be kicked out of the network because they are attacked by malicious nodes, in which case the network topology needs to be updated and maintained accordingly to ensure the stability and reliability of network data transmission. In addition to topology changes, wireless sensor networks may have abnormal situations such as traffic congestion. How to solve the problem quickly and effectively when the abnormal situation occurs is a challenge for routing protocol design.

(3) Reducing redundancy

Wireless sensor networks deploy a large number of sensor nodes in their coverage area considering that sensor nodes are prone to failure. This deployment method causes redundancy in the nodes' sensed data, and the transmission of redundant information increases the energy consumption of the nodes. How to reduce the redundancy of data or exploit the redundancy of data for fault tolerance to improve the overall performance of the network is a difficulty and challenge in the design of routing protocols.

(4) Security issues

Most routing protocols for wireless sensor networks employ the broadcast multi-hop approach for information transmission and exchange, which puts the security of the network at risk. The asymmetric cryptographic regime, which is widely used in traditional wireless networks, is hardly applied in the energy-constrained situation of sensor nodes in wireless sensor networks [5], which presents a challenge and difficulty in designing lightweight routing protocols that guarantee the security of the network.

3.3 The possibility of applying gray theory in WSNs routing protocols

In wireless sensor networks, sensor nodes sense data with different attributes according to various application scenarios, and there are no clear correlations between attribute metrics, no clear correlations between sensor nodes and each other, and no correlations between metrics related to routing protocols. This shows that there is a large amount of incomplete information known about wireless sensor networks. This feature is in accordance with the "information-poor" requirement of gray system theory. The sensor nodes of wireless sensor networks are limited by energy, and the data samples they process are small, which is in line with the "small sample" requirement of the gray system theory. These characteristics of wireless sensor networks provide possibilities for the application of gray system theory. Table 1 summarizes the possibilities of the application of gray theory in the routing protocols of wireless sensor networks.

Table 1. Possibilities of applying gray theory in WSNs routing protocols

Application Scenarios	Gray Correlation	Gray Prediction	Gray Clustering

(2) 稳定性无线传感器网络的节点处于静止状态，因此网络的拓扑结构一般不会改变。一般不会改变[4]。然而，传感器节点可能会受到自身和环境因素的影响而出现故障，或者因为网络中出现的问题而被踢出网络。和环境因素的影响而失效，或者因为受到恶意节点的攻击而需要被踢出网络。他们受到恶意节点的攻击，在这种情况下，需要对网络拓扑结构进行相应的更新和维护，以确保网络的稳定性。在这种情况下，网络拓扑结构需要相应的更新和维护，以确保网络数据传输的稳定性和可靠性。数据传输的稳定性和可靠性。除了拓扑结构的变化之外，无线传感器网络还可能有异常情况，如交通拥堵。当异常情况发生时，如何快速解决异常情况发生时，如何快速有效地解决问题是路由协议设计的一个挑战。设计的挑战。(3) 减少冗余无线传感器网络在其覆盖范围内部署了大量的传感器节点。考虑到传感器节点很容易发生故障。这种部署方法导致节点感知数据的冗余，而冗余信息的传输增加了节点的能量消耗。如何减少数据的冗余或利用数据的冗余进行容错，以提高网络的整体性能是一个难题。是路由协议设计中的一个困难和挑战。(4) 安全问题大多数无线传感器网络的路由协议采用广播多跳的方式进行信息传输和交换，这使得网络的安全性受到威胁。网络的安全受到威胁。在传统无线网络中被广泛使用的非对称加密机制，几乎没有被应用于在传统的无线网络中广泛使用的非对称加密机制，在无线传感器网络中传感器节点的能量受限情况下几乎没有应用。无线传感器网络中的传感器节点[5]，这给设计保证网络安全的轻量级路由协议带来了挑战和困难。

灰色理论在WSNs路由协议中应用的可能性在无线传感器网络中，传感器节点根据不同的应用场景感知不同属性的数据，而属性指标之间没有明确的相关性，传感器节点之间没有明确的相关性，与路由协议相关的指标之间也没有与路由协议相关的度量之间的相关性。这表明，有大量关于这表明有大量的关于无线传感器网络的不完整信息。这一这一特点符合灰色系统理论的 "信息贫乏 "要求。无线传感器网络的传感器节点受到能量的限制，而它们处理的数据他们处理的数据样本很小，这符合灰色系统理论的 "小样本 "要求。灰色系统理论的 "小样本 "要求。无线传感器网络的这些特点为应用灰色系统理论的可能性。表1总结了在无线传感器网络的路由协议中应用灰色理论的可能性。网络中应用灰色理论的可能性。

Energy consumption	Data compression	Possible [12,13]	Extremely likely [12,13,26]	General
	Data Convergence	General	Extremely likely [6-11,18]	General
	Power Management	General	Extremely likely [14-17,24,26]	General
	Redundancy Reduction	Possible [12,13]	Extremely likely [6-18]	General
Reliability	Node Evaluation	Possible [19,21]	Extremely likely [18,20,25]	General [21]
	Path Evaluation	General [22]	General [22]	General [22]
Reliability	Channel Congestion	General	Possible [23,24]	General
	Fault Detection	General	Extremely likely [7,24-26]	General
	Quality of Service	Extremely likely [19,21,22]	Extremely likely [23-25]	Possible [21,22]

4 Application of Gray Theory in WSNs Routing Protocols

4.1 Energy management of WSNs routing protocols

Xiang et al. [6] proposed an energy saving algorithm based on cluster head prediction. Based on the time-dependent nature of the data sent by the nodes within the cluster, the cluster head predicts the data using the gray prediction algorithm based on the existing fused data. If the prediction error is within the threshold value, the node cancels the information transmission to the cluster head. The life cycle of the cluster head is extended by reducing the frequency of communication between the cluster head and the nodes within the cluster. Liang et al. [7] run the dynamic gray prediction algorithm simultaneously at the cluster head and the sink node. The cluster head predicts the future data values based on the existing fusion data, and when the prediction error is less than a set threshold, no data is transmitted for this round. If the sink node does not receive information from the cluster head within the specified time, the predicted data is used as the data transmitted by the cluster head in that round.

In order to distinguish whether nodes are not transmitting data because of failure or because of successful predictions, Wei et al. [8] proposed a dual queueing mechanism to synchronize the sequence of predicted data in sensor nodes and sink nodes. The algorithm combines a gray model and a Kalman filter model, and dynamically adjusts the prediction model by setting the parameter of the number of consecutive prediction successes. The algorithm compares an algorithm that uses an autoregressive model for prediction and a prediction algorithm that uses only the gray model or the Kalman filter model, resulting in a reduction in algorithm complexity, prediction error, and network energy consumption.

In order to solve the problem of prediction accuracy of nonlinear sudden perceptual data and to reduce the computational complexity, Wang, R. Y. et al [9] proposed an algorithm combining GM(1,1) with least squares support vector machine. Since the least squares support vector machine is based on the principle of structural risk mini-

WSNs路由协议的能量管理Xiang等人[6]提出了一种基于簇头预测的节能算法。基于集群内节点发送的数据的时间依赖性。簇头使用灰色预测算法对数据进行预测。现有的融合数据。如果预测误差在阈值之内，节点就会取消对簇头的信息传输。簇头的生命周期通过减少簇头和簇内节点之间的通信频率，延长了簇头的生命周期。和集群内的节点之间的通信频率，从而延长集群头的生命周期。Liang等人[7]在簇头和汇点节点同时运行动态灰色预测算法。簇头预测簇头根据现有的融合数据预测未来的数据值，当预测的误差小于设定的阈值时，本轮不传输数据。如果水汇节点没有在指定的时间内没有收到来自簇头的信息，那么预测的数据就会被用作水汇节点传输的数据。数据被用作群头在该轮中传输的数据。为了区分节点不传输数据是由于失败还是由于预测成功。Wei等人[8]提出了一个双排队机制来同步传感器节点和汇点节点的预测数据序列。该算法该算法结合了灰色模型和卡尔曼滤波模型，并通过设置参数动态地调整通过设置连续预测次数的参数来动态调整预测模型成功的参数。该算法对使用自回归模型进行预测的算法和使用自回归模型进行预测的算法进行了比较。预测的算法与只使用灰色模型或卡尔曼滤波器模型，从而降低了算法的复杂性、预测误差和网络能量消耗。

mization, the algorithm prediction execution time is long. However, the algorithm greatly improves the prediction accuracy using only the gray model.

Xiong et al. [10] proposed an algorithm combining the gray model GM(1,1) with the optimal pruning limit learning machine to address the problem of limited data processing and storage capacity of sensor nodes. The algorithm uses a dual prediction mechanism and employs a single hidden layer feedforward network in the fusion process to speed up the approximation of the predicted values to the true values. Compared with the literature [9], the computational speed of the algorithm has been greatly improved. However, in some cases, its prediction accuracy may be lower than the latter. In order to improve the prediction accuracy, Xiong et al. [11] proposed the algorithm of gray model combined with kernel recursive least squares. The algorithm is simulated on the dataset from Intel Berkeley Research Laboratory, and the results show that the algorithm has improved the prediction accuracy, especially when the study object is a highly nonlinear dataset, and the prediction accuracy and execution time perform well.

Zhu and Duan et al. [12-13] proposed a data compression method based on the structure of cluster head and sink node separation, which requires the nodes within a cluster to collect data at equal time intervals, and then segment the data sequence collected at each interval as well as send some of the segments or each segment of partial data to the respective cluster head. The cluster head performs spatial denoising and data compression on the received data of equal time intervals and then transmits the average value of the data of each time interval to the sink node. Finally, the sink node recovers the data not transmitted by the sensing node using the gray model or an improved gray model. Experiments show that this algorithm can significantly reduce the network energy consumption and extend the network lifetime compared to the terminal node-based compression method.

Wei and Feng et al. [14-15] proposed a dynamic power management approach based on gray model, whose basic ideas were all to predict the state of the sensing area in the future using a gray prediction model, and then to change the working mode of sensor nodes by sink node planning or self-adjustment to achieve the effect of shortening the working time of sensor nodes and thus reducing the energy consumption of the network. Lee et al. [16] proposed a network prediction scheme based on gray prediction and fuzzy inference to adjust the transmission power of sensor nodes. In this scheme, sensor nodes predict the future signal strength of their neighbors using a gray model based on the historical signal strength of neighboring nodes, and then determine the new transmission power level of the nodes using a fuzzy inference system. The scheme maintains the packet transmission rate of the network while reducing the power consumption of the network.

Engmann et al. [17] proposed an improved rolling gray prediction model. The model sets different lengths of node scheduling cycles, while the nodes are turned off when they are not scheduled and turned on when data must be collected. The optimal scheduling cycle is determined by comparing the prediction accuracy and energy consumption of different scheduling cycles. Experiments show that the overall energy consumption of the network is significantly reduced under the optimal scheduling cycle.

为了解决非线性突发性知觉数据的预测精度问题，并降低计算的复杂性为了解决非线性突发感知数据的预测精度问题，并降低计算复杂度，Wang, R. Y.等人[9]提出了一种结合GM(1,1)和最小二乘支持向量机的算法，将GM(1,1)与最小二乘支持向量机相结合。由于由于最小二乘法支持向量机是基于结构风险最小化的原理，算法的预测执行时间较长。然而，该算法仅使用灰度模型就能极大地提高预测精度。Xiong等人[10]提出了一种将灰色模型GM(1,1)与最佳修剪极限学习机来解决传感器节点的数据处理和存储能力有限的问题。处理和存储传感器节点的有限数据。该算法采用了双重预测机制机制，并在融合过程中采用了单隐层前馈网络，以加快近似度。融合过程中采用单隐层前馈网络，以加快预测值与真实值的接近速度。与文献[9]相比，该算法的计算速度有了很大提高。大幅提高。然而，在某些情况下，其预测精度可能低于后者。为了提高预测精度，Xiong等人[11]提出了灰色模型与核递归最小二乘法相结合的算法。该算法在英特尔伯克利研究实验室的数据集上进行了模拟，结果表明结果表明，该算法提高了预测精度，特别是当研究对象是高度非线性的时候。研究对象是一个高度非线性的数据集时，预测精度和执行时间表现良好。时间表现良好。Zhu和Duan等人[12-13]提出了一种基于簇头和水槽节点分离的结构，要求簇内的节点以相等的时间间隔收集数据。该方法要求集群内的节点以相等的时间间隔收集数据，然后将每个间隔收集的数据序列分割成在每个时间间隔内收集的数据，并将其中一些片段或每个片段的部分数据发送到各自的簇头。簇头对收到的数据进行空间去噪和数据压缩。和数据压缩，然后将每个时间间隔的数据的平均值传输给群头。每个时间间隔的数据的平均值传送给汇点节点。最后，汇节点使用灰度模型或改进的灰度模型恢复未被传感节点传输的数据。改进的灰色模型。实验表明，该算法可以显著降低与基于终端节点的压缩方法相比，该算法可以显著降低网络能耗并延长网络寿命。基于终端节点的压缩方法。Wei和Feng等人[14-15]提出了一种动态电源管理方法基于灰色模型的动态电源管理方法，其基本思想都是利用灰色预测来预测传感区域未来的状态。其基本思想是利用灰色预测模型预测未来感知区域的状态，然后通过汇流排节点改变传感器节点的工作模式。通过汇合点规划或自我调整来改变传感器节点的工作模式，达到缩短传感器节点工作时间的效果。缩短传感器节点的工作时间，从而减少网络的能量消耗。Lee等人[16]提出了一种基于网络预测的方案灰色预测和模糊推理来调整传感器节点的传输功率。在这个方案中，传感器节点利用基于历史信号的灰色模型预测其邻居的未来信号强度基于邻居节点的历史信号强度的灰色模型，然后使用模糊推理系统确定节点的新传输功率水平。该方案保持了网络的数据包传输率，同时降低了网络的功耗。Engmann等人[17]提出了一个改进的滚动灰色预测模型。该该模型设置了不同长度的节点调度周期，而节点在未被调度时被关闭，而在调度时被打开。当它们没有被调度的时候关闭，当必须收集数据的时候打开。最佳的最佳调度周期是通过比较不同调度周期的预测精度和能耗来确定的。不同调度周期的能量消耗。实验表明，网络的总体能量在最佳调度周期下，网络的整体能耗显著降低。周期。

Dai et al. [18] concluded that the GM(1,1) model is less stable and proposed an algorithm for data fusion using a discrete gray model. The algorithm uses the Grubbs detection algorithm to exclude the outliers within the clusters, and runs the data fusion scheme based on the discrete gray model simultaneously at the cluster head nodes and the convergence nodes. Experiments show that its prediction is better than the algorithm proposed in [11].

Dai等人[18]认为GM(1,1)模型的稳定性较差，提出了一种使用离散灰色模型的数据融合算法。该算法使用Grubbs该算法使用Grubbs检测算法来排除聚类中的异常值，并运行基于离散灰色模型的数据融合并在簇头节点和汇聚节点同时运行基于离散灰色模型的数据融合方案。收敛节点上同时运行基于离散灰色模型的数据融合方案。实验表明，其预测效果优于[11]中提出的算法

4.2 Trust evaluation of WSNs routing protocols

Hong et al. [19] proposed a reputation calculation method on neighbor screening for the possible abuse of neighbor discovery in WSNs routing protocols. The algorithm selects the attributes of nodes such as signal strength, packet loss rate and average transmission delay, sets the optimal set and the inferior set, calculates the association of nodes with the optimal node and the inferior node, and finally the obtained optimal association and inferior association determine whether the evaluated node is good enough to be elected as a neighbor node.

A reputation assessment model based on a gray Markov model was designed by Zeng et al. [20]. The model uses a gray Markov model to analyze the reputation of nodes longitudinally. The predicted reputation values are first calculated using the gray model based on the historical reputation sequences of the nodes. Then the predicted values are corrected using the Markov model to obtain the longitudinal reputation values of the nodes. The combined reputation value of nodes combines direct reputation, indirect reputation and energy reputation.

Beghriche et al. [21] proposed a fuzzy trust-based routing algorithm based on the AODV [22] algorithm. The end-to-end delay, node residual energy, packet loss rate, throughput rate and hop count are selected to construct a gray correlation set and calculate the gray correlation degree of each metric. Based on the gray clustering analysis, the trust value level of nodes is calculated, which is used for the final routing decision. Experiments show that the algorithm performs well in terms of packet delivery rate, end-to-end delay, routing overhead and energy consumption.

Li et al. [23] proposed a trust path screening and aggregation algorithm based on the gray-Hidden Markov model for the path selection problem. The algorithm uses gray correlation analysis to measure the similarity between the evaluation behavior of the evaluated entity and the recommended entity, as well as classifies the evaluated entity, the recommended entity and the evaluated object into four clustering patterns based on the similarity. The algorithm employs a possibility function with evaluation similarity as the independent variable to find the acceptance degree of the recommended entity, and then recursively obtains the acceptance degree of the path, as well as predicts the gray class state in which the gray recommended path is located. The algorithm screens multiple gray recommendation paths based on the Hidden Markov Model and selects the optimal path.

WSNs路由协议的信任评估Hong等人[19]提出了一种关于邻居筛选的信誉计算方法。WSNs路由协议中邻居发现的可能滥用。该算法选择节点的属性，如信号强度、丢包率和平均传输延迟。传输延迟，设置最优集和劣质集，计算节点与最优节点的关联度。计算节点与最优节点和劣质节点的关联，最后根据获得的最优最后根据获得的最优关联和劣质关联确定被评估的节点是否足够好足够好，可以被选为邻居节点。Zeng等人设计了一个基于灰色马尔可夫模型的声誉评估模型。Zeng等人[20]。该模型使用灰色马尔可夫模型来分析节点的声誉。节点的声誉。预测的声誉值首先是使用基于节点的历史声誉序列，首先使用灰色模型计算预测值。然后用马尔可夫模型对预测值进行修正，得到节点的纵向声誉值。节点的综合信誉值包括直接信誉、间接信誉和能源信誉。声誉、间接声誉和能源声誉。Beghriche等人[21]提出了一种基于模糊信任的路由算法，该算法基于AODV[22]算法。端到端延迟、节点剩余能量、丢包率。吞吐率和跳数被选来构建灰色关联集，并计算每个指标的灰色关联度。基于灰色聚类分析，计算出节点的信任值水平，用于最终的路由决策。决策。实验表明，该算法在数据包交付率、端到端延迟、路由开销和能量消耗方面表现良好。Li等人[23]提出了一种基于信任路径筛选和聚合算法的灰色隐藏马尔可夫模型的路径选择问题。该算法使用灰色关联分析来衡量被评价实体和推荐实体的评价行为之间的相似度。灰色关联分析来衡量被评价实体和被推荐实体的评价行为的相似性，并对被评价实体、被推荐实体和被评价实体进行分类。灰色关联分析来衡量被评价实体和被推荐实体的评价行为的相似性，并将被评价实体、被推荐实体和被评价对象分为四个聚类模式基于相似度，将被评价实体、推荐实体和被评价对象分为四种聚类模式。该算法采用了一个可能性函数，以评价相似度为自变量，求出推荐实体的接受度，然后递归得到路径的接受度，以及并预测灰色推荐路径所处的灰类状态。该算法算法根据隐马尔可夫模型筛选出多个灰色推荐路径，并选择最优路径。模型，并选择最优路径。

4.3 Exception handling of WSNs routing protocols

Tang et al. [24] proposed a control algorithm based on gray predictive neural networks to control queues to address the problem that most of the congestion control strategies or algorithms in WSNs do not consider the data round-trip transmission delay. In the large time lag network, the gray model predicts the future queue length change of the sink node. Based on the prediction, the radial basis function neural network adjusts the algorithm parameters online using the self-learning capability to stabilize the queue length around the desired value. This method reduces the impact of time lag on the network delay and avoids congestion at the aggregation nodes.

Chen et al. [25] proposed a congestion detection and control algorithm based on short-term prediction of cluster head data throughput for the local congestion problem of hierarchical topologies of wireless sensor networks. The algorithm specifies that the cluster head employs a gray prediction model to analyze the current data traffic and predict its own future congestion level, adjusting the data collection frequency of the nodes in the cluster when the predicted value is higher than a certain threshold. The algorithm reduces the data transmission pressure on the cluster head and controls the network congestion.

Zhang et al. [26] proposed a distributed network fault detection algorithm based on gray prediction using the neighbor collaboration mechanism. The algorithm collects data sets of the evaluated node and its neighboring nodes over a period of time and compares the difference between the predicted data of the evaluated node and the weighted mean value of the predicted data of the neighboring nodes to determine whether the evaluated node is abnormal. Compared with the traditional fault detection algorithm based on data mining theory, the algorithm is much less computationally intensive and easy to implement.

An anomaly detection algorithm based on compressed sensing and GM(1,1) is proposed by Li et al. [27]. The algorithm proposes a block-based step-size adaptive signal reconstruction algorithm for sensor nodes with unknown sparsity of sensed data. GM(1,1) predicts the possible anomalies in the next cycle based on the reconstructed data. The sink node sends messages to adjust the nodes' working state. The algorithm compares the anomaly detection algorithm without prediction, and the false alarm rate, missed detection rate and energy consumption are reduced.

WSNs路由协议的异常处理
Tang等人[24]提出了一种基于灰色预测神经网络的控制算法来控制队列，以解决大多数WSN中的拥塞控制策略或算法不考虑数据往返传输的问题。大多数WSN的拥塞控制策略或算法没有考虑数据往返传输的延迟。延迟。在大时滞网络中，灰色模型预测了未来队列长度的变化。在预测的基础上，径向基函数神经网络利用自学能力在线调整算法参数，以便将队列长度稳定在期望值附近。这种方法减少了该方法减少了时间滞后对网络延迟的影响，避免了聚合节点的拥堵。Chen等人[25]提出了一种基于拥塞检测和控制的算法。簇头数据吞吐量的短期预测来解决无线分层拓扑结构的局部拥堵问题。的分层拓扑结构的无线传感器网络。该算法规定簇头采用灰色预测模型来分析当前的数据流量并预测自己未来的拥堵程度，当集群中的节点出现拥堵时，调整其数据采集频率。当预测值高于某个阈值时，调整集群中的节点的数据收集频率。该算法减少了簇头的数据传输压力，控制了网络拥堵。Zhang等人[26]提出了一种分布式网络故障检测算法，该算法基于使用邻居协作机制的灰色预测。该算法收集了该算法收集被评估节点及其邻居节点在一段时间内的数据集并比较被评估节点的预测数据和被评估节点的加权平均值之间的差异。邻居节点预测数据的加权平均值来确定判断被评估的节点是否有异常。与传统的故障检测算法相比与传统的基于数据挖掘理论的故障检测算法相比，该算法的计算量要小得多，而且容易实现。密集，且易于实现。Li等人提出了一种基于压缩传感和GM（1,1）的异常检测算法[27]。该算法提出了一种基于块的步长的自适应信号重建算法，适用于传感数据稀疏度未知的传感器节点。GM(1,1)根据重建的数据预测下一个周期可能出现的异常情况。数据。汇点节点发送消息以调整节点的工作状态。该算法与没有预测的异常检测算法进行比较，其误报率、漏报率和能耗都很低。误报率、漏检率和能耗都有所降低。

5 Summary and Outlook

This paper introduces the concepts related to gray system theory and WSNs routing protocols, analyzes the characteristics of current WSNs routing protocols and the challenges they face, studies the possibility of applying gray system theory in WSNs routing protocols, and finally analyzes and summarizes the existing algorithms for the application of gray system theory in WSNs routing protocols.

As can be seen from Table 1, at this stage, gray system theory is mainly applied to energy consumption, trust evaluation, and anomaly detection of WSNs routing protocols. The application methods focus on gray correlation analysis and gray prediction analysis. There are fewer applications about gray clustering algorithms. Table 2 spe-

本文介绍了灰色系统理论和WSNs路由协议的相关概念。协议，分析了当前WSNs路由协议的特点和面临的挑战。灰色系统理论在WSNs中应用的可能性。路由协议中应用灰度系统理论的可能性，最后分析并总结了现有的算法，以促进灰度系统理论在WSN中的应用。最后分析总结了现有的灰色系统理论在WSNs路由协议中的应用。从表1可以看出，现阶段，灰色系统理论主要应用于能耗、信任评估和WSNs路由协议的异常检测。应用方法主要是灰色关联分析和灰色预测分析。关于灰色聚类算法的应用较少。表2专门分析了通过引入灰色系统理论对WSNs路由协议算法的增强。

cifically analyzes the enhancement of WSNs routing protocol algorithms by the introduction of gray system theory.

Table 2. Performance improvement of WSNs routing protocols by gray system theory

Algorithms	Enhancement Strategies	Comparison algorithms	Efficiency improvement
[6-7,18]	Reducing data transfer through prediction	LEACH[28]	Network lifecycle extended by more than 28%
[8-11]	Improving initial predictions with algorithms such as Kalman filter and support vector machine	Autoregressive	Improvement in prediction accuracy Reduction of algorithm execution time
[12-13]	Extracting odd or even sequences of GM(1,1) to reduce prediction error	Linear regression Adaptive Polynomial Fitting	When the compression ratio is less than 50%, the root mean square error is smaller
[14-15,17]	Adjust sensor node operating mode by prediction to reduce node operating hours	Wavelet autoregressive	Network lifecycle extended by approximately 20%
[16]	Adjustment of node transmission power by prediction	Markov-based transmission power control algorithm	Similar network energy consumption Algorithm complexity is greatly reduced
[19]	Screening nodes by gray correlation analysis	Neighborhood discovery based on signal strength	No need for clock synchronization and GPS, high neighbor discovery accuracy
[20]	Predicting future reputation based on node historical reputation	BRSN[29]	10% reduction in network energy consumption
[21]	The selection of evaluation indexes combines gray correlation analysis and fuzzy analysis	TAODV[30]	Improvements in packet delivery rate, path overhead and energy consumption
[23]	Determine the confidence of the recommended path based on the clustering distribution of neighboring entities	Node bidding method based on entropy power and TOPSIS [31]	Malicious entity separation success rate has improved
[24-25]	Adjust work status by predicting future data flow of nodes	CODA[32]	10% reduction in cache footprint and 10% energy savings
[26]	Predicting the difference in future performance of nodes and neighboring nodes	Fault detection algorithm based on data mining theory	Fault detection rate improved by 0.5% and false alarms reduced by 33%
[27]	Reconstruction of raw data to predict possible future anomalies	Autoregressive	False alarm rate, missed detection rate and energy consumption have been reduced

It can be seen that the introduction of gray system theory improves the performance of WSNs routing protocols. Further analysis reveals that the application of gray system theory is mainly in the following aspects.

(1) Improving the original algorithm by using the features of gray system theory. The specific analysis is shown in Table 3.

可以看出，灰色系统理论的引入提高了WSNs路由协议的性能。进一步分析发现，灰色系统理论的应用主要体现在以下几个方面。(1) 利用灰度系统理论的特点对原有算法进行改进。具体分析见表3。

Table 3. Analysis of the principle of gray model introduction

Algorithms	Principle	Gray model used
[6-7,18]	Prediction reduces the number of data transfers	GM(1,1), Dynamic GM, Discrete GM
[19,26]	The behavior of neighboring sensor nodes has some similarity	The gray correlation model, GM(1,1)
[20]	The trust value of a node changes over time	GM(1,1)
[23]	Clustering evaluation performs more objectively when the node composition is unknown	Gray clustering evaluation
[25]	The data traffic of the network has a certain pattern	GM(1,1)

(2) The original algorithm is improved with a single gray model using the excellent performance of the gray model in similar models and algorithms. The main comparison algorithms are autoregressive algorithms, linear regression, and polynomial fitting algorithms.

2）用单一的灰度模型改进原始算法，利用灰度模型在类似模型和算法中的出色表现。灰色模型在类似模型和算法中的表现。主要的比较算法有自回归算法、线性回归、多项式拟合等算法

Table 4. Analysis of the algorithm using the single gray model

Algorithms	Comparison Algorithm	Advantage Analysis
[12-13]	Linear Regression, Adaptive Polynomial Fitting	The gray model does not affect the prediction by removing some data
[14-15,17,27]	Wavelet autoregressive	Gray model has good adaptability to local anomalous data
[16]	Markov model	Gray models do not require extensive detailed data modeling
[21]	Customized trust clustering methods	Gray clustering analysis is more objective than the algorithm of artificial clustering

(3) To address the shortcomings of the gray model, combine with other algorithms to optimize the gray model to achieve the desired effect.

Table 5. Deficiencies of the gray model and improvement of the model

Algorithms	Shortcomings	Combined algorithms
[8]	Gray models have difficulty identifying interfering data	Kalman filtering
[9-11]	Gray prediction model is less effective in predicting nonlinear burst data	Machine Learning
[20]	Gray prediction model is less effective in predicting data with high random volatility	Markov model
[24]	The gray prediction model has a longer prediction time	Radial basis function neural network

As can be seen from Table 1, the application of gray clustering analysis in WSNs routing protocols is relatively small. As a clustering analysis method, gray cluster analysis does not require a special distribution of data sequences and is computation-

从表1可以看出，灰色聚类分析在WSNs中的应用路由协议中的应用是比较少的。作为一种聚类分析方法，灰色聚类作为一种聚类分析方法，灰色聚类不需要特殊的数据序列分布，而且计算简单，所以研究其在WSNs路由协议中的应用是很有前景的。此外此外，WSNs路由协议是无线传感器网络领域的一个重要分支。传感器网络领域的一个重要分支。除了路由技术，无线传感器网络的节点定位技术、时间同步技术、网络安全技术、网络拓扑控制等都是重要的技术。网络拓扑控制都是WSNs领域的重要技术。它是研究灰色系统理论在许多重要技术中的应用同样重要。技术中的应用，这为该领域的学者提供了一个新的研究课题。

ally simple, so it is promising to study its application in WSNs routing protocols. In addition, WSNs routing protocols are an important branch in the field of wireless sensor networks. Besides routing technology, wireless sensor network node localization technology, time synchronization technology, network security technology, and network topology control are all important technologies in the field of WSNs. It is equally important to study the application of gray system theory in many important technologies, which provides a new research topic for scholars in this field.

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