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# A real-time data compression algorithm for gear fault signals

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ABSTRACT

A flexible, stable and controllable real-time algorithm of Auto-Regressive and Moving Average based on Swing Door Trending (ARMA-SDT) is proposed for the compression of impact-type signals in gear fault detection systems. The Auto-Regressive and Moving Average (ARMA) model is used to predict the variation trend of signal features. To guarantee the adaptability, an empirical equation is proposed to calculate the compression threshold of the Swing Door Trending (SDT). Based on the empirical equation and prediction results, dynamic self-regulation of compression threshold is realized, and the compression error always stays around a preconfigured value. Moreover, an experimental setup and an engineering solution are proposed to verify the usefulness, reliability, and stability of the proposed ARMA-SDT algorithm in data compression.



## 1. Introduction

Condition monitoring and fault diagnosis systems for the mechanical equipment have been extensively studied in recent years. The demand for these systems in the civil and military field grows with each passing day [1–4]. As one of important mechanical sub-systems, a gearbox mainly includes gears, bearings and shafts. Although the bearings have a high percentage of failures [5], the gears have the highest percentage of failures among the components of the gearbox [6]. Hence, the research works carried out at gear fault detections have practical significance for the equipment maintenance and sudden accident prevention. In the past decades, many researchers have done considerable works in the fault detection of gears and their related driven systems [7–9]. Commonly, the time domain [10–12], frequency domain [13–15], time frequency domain based on STFT [16], wavelet transform [17], time synchronous averaging [18] and other signal processing techniques have been implemented and tested. Moreover, new approaches of intelligence techniques for the diagnosis have experienced over the past few years, such as the neural networks [19,20], support vector machines [21], machine learning based of data mining [22] and hybrid fault diagnosis techniques [23]. In general, the vast majority of existing research works were focused on the signal processing and feature extraction, fault mechanism, intelligent decision and diagnosis. As the important guarantee and premise to the above three areas, it is worth noting that a good data acquisition and an appropriate signal pre-processing are also pivotal for fault detection system. The accuracy, reliability and completeness of sensing data from monitoring points are original and crucial factors in determining the availability of the gear fault detection methods. Although there were some achievements in the data acquisition and pre-processing [24–26], with the machinery structure becomes more large-scale, integrated, intelligent and complicated, performance indicators of the gear fault detection system are rising, such as the more data collection nodes, higher sampling precision, and higher sampling rate. Therefore, a large number of real-time data lead to significant pressure on data storage, transmission and processing. Furthermore, due to the spe-

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cial mechanical environment, it is common to use the wireless sensor technology to obtain signals from the key points [27,28]. In this situation, the mass data increases the possibility of the network congestion. Therefore, it is necessary to find a real-time data compression method to improve the efficiency of data acquisition and pre-processing of the gear fault detection.

The lossy compression is commonly used in the mechanical signal monitoring [29]. In this field, piecewise-linear trending and compression methods are relatively mature. The Box Car algorithm [30] and Swinging Door Trending (SDT) [31] are representative basic research results in this area. The SDT compression algorithm can be implemented quickly and easily in the field of engineering [32]. The Piecewise Linear Online Trending (PLOT) [33] is an improved SDT algorithm, which realized outlier elimination and adaptability to process variability, whereas it takes up more system resources due to its complexity. To obtain a better compression performance of the Box Car algorithm [34], a method is suggested by tuning the parameters dynamically, and in [35] an on-line tuning algorithm for the threshold window size is presented. In Ref. [36], an algorithm named ISDT is used to increase the compression ratio of SDT by regulating the tolerances according to the length of compression interval, but it comes with a higher misjudgment ratio for outliers. In Ref. [37], an automatic accuracy control SDT algorithm is put forward to make the compression ratio increase by 60–75 percent, though its control precision may drift. Then, through the introduction of the least squares fitting, the computing speed of SDT is improved by the SDLST algorithm. And the SDLST algorithm is used in the Missile State Data Compression [38] and CNC monitoring platform [39]. Basically, most of the methods aforementioned have analyzed and optimized selection ways of the compression threshold from different aspects, but the input parameters configuration of these algorithms is still a difficult task. Furthermore, there is a bigger problem that the efficiencies and reliabilities of these compression methods can be greatly affected by the randomness, non-stationary or strong noise of the mechanical fault signals.

To overcome all the above mentioned drawbacks, a new real-time compression algorithm of Auto-Regressive and Moving Average based on the Swing Door Trending (ARMA-SDT) is proposed in this paper. The ARMA prediction model [40] is used to predict the eigenvalues of the next data segment. The ARMA-SDT can automatically predict the variation trend of a signal. To adapt different kinds of impact-type gear fault signals, the ARMA-SDT uses an empirical equation to compute a compression threshold for the subsequent data, so that it can dynamically regulate its compression threshold based on the prediction results of the ARMA. Moreover, as a constraint, there is a preset compression error in the empirical equation. Therefore, the ARMA-SDT can make the compression error stay around a preset value in the whole compression process. In contrast to traditional piecewise-linear compression algorithms, the ARMA-SDT is more flexible, and it improves reliability of compressed data and provides a guarantee for subsequent fault analysis. An engineering solution for the ARMA-SDT is proposed, which is successfully implemented on the proposed experimental setup. Moreover, this algorithm can be used to process a variety of signals whose characteristics can be extracted easily, i.e., as long as the empirical equation can be extracted, the ARMA-SDT can be used to compress real-time signals.

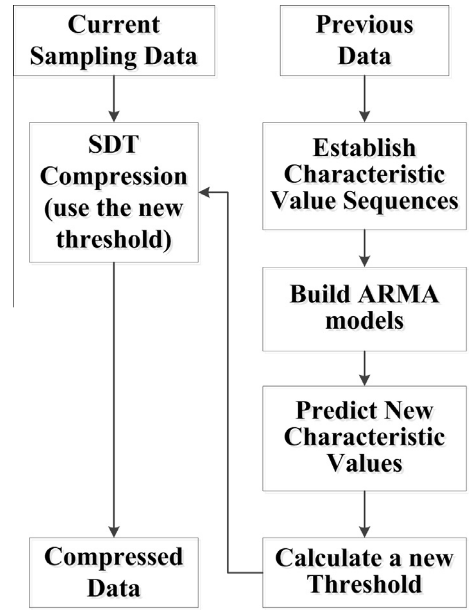


**Fig. 1.** A brief flowchart of the proposed ARMA-SDT algorithm.

## 2. The proposed ARMA-SDT algorithm

The traditional Swing-Door Trending (SDT) [31] is a mature piecewise linear compression algorithm. It can compose a critical window based on the compression threshold $\Delta E$ quickly and decide which point to archive in real time. The compressed data is a subset of the original data. However, the threshold $\Delta E$ is a fixed parameter, and it is easy to deviate from the variation trend of a process signal. This drawback of the SDT may lead to poor compression performance. Therefore, SDT is difficult to adapt the compression of the mechanical signals.

In the proposed ARMA-SDT algorithm, the autoregressive moving average (ARMA) model [40] is added in the SDT to adjust the threshold value $\Delta E$. The brief flow chart of the ARMA-SDT is shown in Fig. 1. The ARMA models are modeled based on the characteristic value sequences to predict the characteristic values of the subsequent data. The stable compression performance can be realized by adjusting the $\Delta E$ adaptively. In order to adjust the threshold, an empirical equation is proposed to calculate the value of $\Delta E$ on the basis of predicted characteristic values.

### 2.1. The characteristic parameters used in the ARMA-SDT algorithm

According to the requirements of real-time compression, characteristics of the effective value $RMS$, kurtosis $K$,