Data Compression for Tele-Monitoring of Buildings

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Abstract

In Africa there has been an increase in construction of new buildings. In many cases, these buildings are constructed at a rate where the local authorities have no capacity to enforce any building code, ethics or standards. To compound this problem, there is a predominant lack of qualified staff on the ground to conduct proper physical inspections in the building sites. One solution to this problem is to utilise tele-monitoring of buildings whereby building data is transmitted over a network for remote interpretation by an expert in a different location. A common form of telecommunication is broadband which is not always straightforward to use in Africa. In this paper we propose wavelet analysis as a data compression technique to transform the building monitor data into trends to address the challenges of broadband in Africa for data transmission and allow qualitative reasoning at the receiving site for building decision support.

Keywords

Wavelets, data compression, building, tele-monitoring

1. Introduction

In Africa, there is a lack of building expertise and a lack of standards in the construction industry (Wells, 1986; Abate, 1997). One solution to this problem is to use tele-monitoring of buildings whereby building data is transmitted over a network for remote interpretation by an expert in another location. One of the mediums for tele-monitoring of buildings is broadband, which, in turn, presents further challenges in Africa which need to be addressed. Due to the capital costs, a common problem associated with broadband in Africa is the lack of telecommunication infrastructure. Consequently, bandwidth demand can easily outstrip the revenue realizable that is needed to pay for the network infrastructure investment (Freeman, 2005). As a result, many rural areas in Africa generally have lower bandwidth than urban areas because it is cheaper – this makes data transfer slow. Moreover, there will be service contention on the restricted bandwidth even if core bandwidth exists to deliver the services because aggregate bandwidth will be generally greater than can be delivered over the access connection (Stallings, 2007). One approach to deal with these challenges is to use data compression. Data compression can be defined as the act of encoding large files in order to shrink them down in size and in doing so the intelligence present in the information is preserved (Ahmad, 2002).

In this paper we propose wavelet analysis as a lossy data compression technique to help alleviate the challenges of broadband in Africa for building operators. The data compression in the form of trends will serve 2 purposes: better use of broadband for transmission of monitored building data since smaller files take up less room and are faster to transfer over a network; and to facilitate qualitative reasoning of the trends by building operators and specialists at the receiving site for building decision support.

The structure of this paper is as follows. Section 2 describes the wavelet analysis algorithm for data compression. Section 3 discusses the results of applying wavelet analysis to data taken from the monitors of a building. A discussion of how wavelets analysis can be used to address the challenges of building operators and the challenges of broadband is given in section 4. Final conclusions are given in section 5.

2. Wavelet Analysis

Wavelet analysis is a mathematical technique that can be used to extract information from many different kinds of data. A wavelet is a wave-like oscillation with amplitude that starts out at zero, increases, and then decreases back to zero. It can typically be visualized as a *brief oscillation* like one might see recorded by a building monitor.

Wavelet analysis is a lossy data compression technique which concedes a certain loss of accuracy in exchange for greatly increased compression. Wavelets can be adjusted to different quality levels, gaining higher accuracy in exchange for less effective compression.

In wavelet analysis, the scale that we use to look at data plays a special role. Wavelet algorithms divide a given function or continuous-time signal into different scale components. One can assign a frequency range to each scale component. Each scale component can then be studied with a resolution that matches its scale. If we look at a signal with a small window, we would notice small features. Similarly, if we look at a signal with a large window, we would notice gross features. There has been a requirement for more appropriate functions than the sines and cosines that comprise the bases of Fourier analysis, to approximate choppy signals.

Generally, Wavelet transform of signal *f* using wavelet Ψ is given by:

$$W_{\psi}(f)(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t)\psi\Big(\frac{t-b}{a}\Big)dt \qquad (1)$$

where the variable *a* is the dilation factor, variable *b* is the translation factor and *a* and *b* are real numbers.

The wavelet analysis procedure is to adopt a wavelet prototype function, called an analyzing wavelet or mother wavelet. Temporal analysis is performed with a contracted, high-frequency version of the prototype wavelet, while frequency analysis is performed with a dilated, low-frequency version of the same wavelet. We will now describe the wavelet method.

Assume that $Y(t)$ is the value of an observable time series at time t, where t can take on a continuum of values. $Y(t)$ consists of two quite different unobservable parts: a so-called trend $T(t)$ and a stochastic component $X(t)$ (sometimes called the noise process) such that

$$Y(t) = T(t) + X(t) \quad (2)$$

where it is assumed that the expected value of $X(t)$ is zero. There is no commonly accepted precise definition for a trend, but it is usually spoken of as a nonrandom (deterministic) smooth function representing long-term movement or systematic variations in a series. Priestly (1981) refers to a trend as a tendency to increase (or decrease) steadily over time or to fluctuate in a periodic manner while Kendall (1973) asserted that the essential idea of a trend is that it shall be smooth. The problem of testing for or extracting a trend in the presence of noise is thus somewhat different from the closely related problem of estimating a function or signal $S(t)$ buried in noise. While the model $Y(t) = S(t)+X(t)$ has the same form as equation (2), in general $S(t)$ is not constrained to be smooth and thus can very well have discontinuities and/or rapid variations.

The detection and estimation of trend in the presence of stochastic noise arises in building monitor data as presented in this paper. Wavelet analysis is a transformation of $Y(t)$ in which we obtain two types of coefficients: wavelet coefficients and scaling coefficients - these are sometimes referred to as the *mother* and *father wavelet coefficients* respectively. The wavelets are scaled and translated copies (*father wavelets*) of a finite-length or fast-decaying oscillating waveform (*mother wavelet*).

The mother and father wavelets coefficients are fully equivalent to the original time series because we can use them to reconstruct $Y(t)$. Wavelet coefficients are related to changes of averages over specific scales, whereas scaling coefficients can be associated with averages on a specified scale. The information that these coefficients capture agrees well with the notion of a trend because the scale that is associated with the scaling coefficients is usually fairly large. Trend analysis with wavelets is to associate the scaling coefficients with the trend $T(t)$ and the wavelet coefficients (particularly those at the smallest scales) with the noise component $X(t)$.

Generally, in wavelet analysis, sets of wavelets are needed to analyze data fully. A set of *complementary* wavelets will deconstruct data without gaps or overlap so that the deconstruction process is mathematically reversible – this is useful for our application because the receiver of the compressed data can perform decompression to obtain the original signal albeit with some information missing.

3. Results

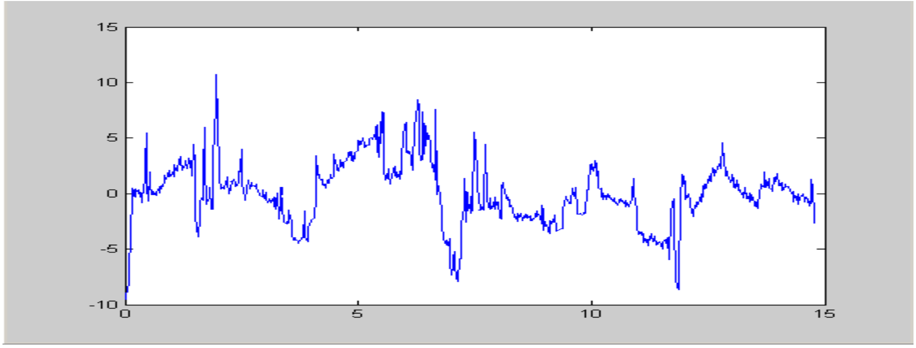

Figure 1: Original/Raw Data Set

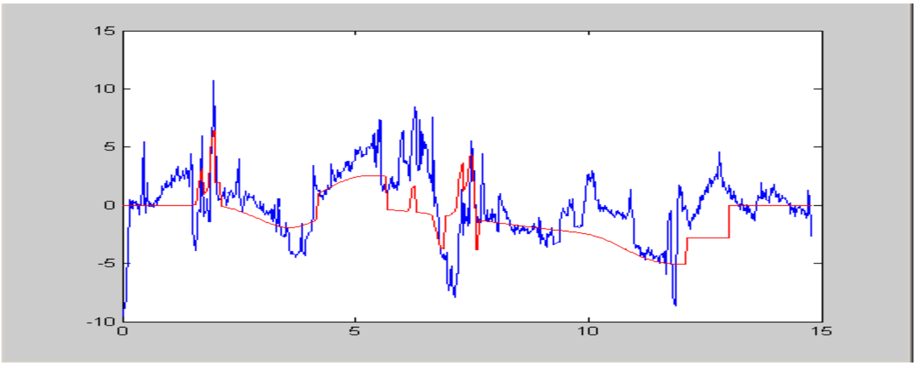

Figure 2: Compressed Data after Wavelet Analysis

To demonstrate the results of wavelet analysis, figure 1 shows the waveform of a Heat Flux signal at 15 - 20Hz recorded in a building in the UK. The bandwidth required for transmission of this digital signal is 20Hz. Heat flux was measured in a building in the United Kingdom with unfired clay bricks for two reasons: to determine the u-value of the wall (how well insulated the wall is); and to determine the admittance of the wall (change in heat flow at the surface ÷ change in wall surface temperature).

The final trends after applying wavelet analysis are shown in figure 2. Trend analysis with wavelets is to associate the Father coefficients (red) with the trend T(t) and the wavelet coefficients (blue). Figure 2 clearly marks the data trend when the data was analyzed with Shannon and Daubechies wavelets. It can be seen that wavelet analysis removes redundancy in the data such as noise caused by external events. It is these trends that are transmitted over the network to the receiver site for interpretation by building operators or specialists. The compression will reduce the bandwidth of the signal and the transmission channel can therefore accommodate more signals which will make better use of resources.

4. Discussion

There are a number of data compression techniques that have been used to make better use of network resources - they include pipelined in-network compression (Arici et al, 2003), coding by ordering (Petrovic et al, 2003) and distributed compression (Kusuma et al, 2001). It has also been shown that data compression for network data transmission cuts the bandwidth needed, improves response size and response delays in networks (Mogul et al, 1997).

We have shown that wavelets analysis can be used as a lossy data compression technique for tele-monitoring of building data. Wavelet analysis allow for more efficient use of network resources because the resulting compressed data reduces storage requirements and makes better use of bandwidth since smaller files take up less room on the access pipe and are therefore faster to transfer over a network. Data compression is therefore ideal for tele-monitoring of building data in Africa because it makes better use of lower bandwidth and contention of services at the monitored building site. In our results we have also shown that our approach serves to remove redundancy in the data such as noise caused by external events.

Since a set of complementary wavelets deconstruct data without gaps or overlap, their mathematical properties make the deconstruction process reversible, albeit with loss of data. If the receiver does not wish to perform decompression then they can perform qualitative reasoning of the trends for building decision support. In (Salatian and Taylor, 2011) it has been shown that qualitative reasoning of trends can be used for fault detection of buildings - here an expert system using associational rules applied to trends was developed to determine periods when there was a fault in the monitored building. Likewise, in (Salatian et al, 2011) the trends generated by wavelets was used to create a conceptual model of a building - this model allows specialists and building operators to determine the current state of a building under observation in order to make informed decisions.

5. Summary and Conclusions

There is a lack of building expertise in Africa which can be addressed by transmitting building data over a network for remote assistance by an expert in another location. However, the transmission of data is not straightforward because there are problems associated with broadband in Africa, especially in rural areas. To address these challenges we have proposed in this paper using wavelet analysis as a data compression technique to transform the building monitor data into trends.

Wavelet analysis is a lossy data compression technique to provide qualitative measurements in the form of trends from the voluminous, high frequency and noisy data that is generated by the monitors in a building. The transmitted trends make better use of restricted broadband and facilitate building specialists at the receiving site to perform qualitative reasoning of the trends for building decision

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