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On the effect of compression on the complexity characteristics of wireless acoustic sensor network signals

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ABSTRACT

A microelectronic system for monitoring areas of environmental interest through the automated creation of soundmaps, based on data from a wireless acoustic sensor network (WASN) has been recently proposed. In this context, it has been demonstrated that compression algorithms need to be employed at sensor node level due to the increasing demand in bandwidth as the number of sensors and events to be logged increases. Motivated by this finding, the effect of data compression on signal complexity is studied in this paper by employing four widely used audio compression algorithms in combination to different entropic/information measures. Several entropic/information measures are calculated for both compressed data streams and the original audio, leading to a comparison on the effect of the compression on the complexity characteristics of WASN signals. Numerical results imply that in a realistic WASN for environmental monitoring it is possible to locally compress audio data at node level prior to network transmission while maintaining the complexity characteristics of the sound signal in terms of preserving the precision of specific entropic/information metrics. However, this is not possible for all the studied "complexity metric-compression algorithm" combinations.

1. Introduction

Human-generated pollution, over-population and climate change have generated the need to better understand natural ecosystems, their complex interactions and the impact of urban and industrial expansion upon them [1,2]. Since human development dramatically affects components and linkages within ecosystems, thus altering their function and structure, it has been long ago proposed to monitor certain ecological indicators on a continuous and periodical basis in order to monitor these changes [3]. Recently, it has been proposed that acoustic features are also an ecological attribute that can potentially increase our understanding of ecosystem change in terms of deviations from conventional ambient sound or regular discrete sound events [4,5]. In the EU, the European Commission has adopted directives on the assessment and management of noise [6], while in the USA, state and federal agencies, like the Michigan Department of Labor and Economic Growth, United States Fish and Wildlife Service and the National Park Service, have stressed out the need to measure the temporal variability of acoustic pollution [2].

The *Soundscape* is a novel term that intends to describe the equivalent of landscapes in the case where the information content is auditory rather than visual; it has been defined as "*the collection of biological, geophysical and anthropogenic sounds that emanate from a landscape and*

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which vary over space and time reflecting important ecosystem processes and human activities" [7] or "*a sonic environment that is perceived by a human or a society*" [8]. Sound features encapsulate information that can be combined with the visual features of the landscape, thus leading to useful environmental conclusions [9–12]. A regularly updated sound recording over a certain region of environmental interest on different time periods may depict its sound content and be used for the detection of changes in an ecosystem. Soundscape monitoring is usually linked with targeted efforts to employ sound classification and signal processing techniques on identifying inhabiting species and human passers-by, with intensive effort having been put to bird species recognition, forensics analysis and other applications [13–17].

Recent advances in wireless communications, networks and integrated sensors, have provided the ability to use Wireless Sensor Networks (WSNs) in order to monitor large areas with a dense network of inexpensive nodes that collectively transmit information to a central server in real-time. WSNs have been demonstrated to exhibit the potential of being used in massive scale for environmental monitoring, with a large variety of sensor types that can record different environmental features. In particular, the term WASN is introduced (Wireless Acoustic Sensor Network) in order to indicate the particular challenges of a WSN. In WASNs, the information load is orders of magnitude larger compared to networks with low sampling rate sensor nodes (e.g. temperature or humidity sensors). In this respect, WASNs lie between conventional WSN and Wireless Multimedia Sensor Networks (WMSNs) in terms of computational and information load [20,21].

The ESOUNDMAPS project aims at developing a proof-of-concept platform of sound measurements, classification and mapping at areas of environmental interest based on a Wireless Audio Sensor Network (WASN) [18,19,22]. Due to the non-stationary nature of the sound information, soundmaps require regular periodic update in order to provide a reliable monitoring tool [19]. In a WASN, as the number of sensor nodes and the sound events to be logged increase, so does the necessary bandwidth for wireless transmission of data to the central processing server [22]. In the frame of the ESOUNDMAPS project, a simulation-based study on the stability of such a WASN in relation to the active recording time, and the input load per node, resulting from different possible compression rates, has been recently presented (see also Section 2) [22]. The results obtained by the performed simulations, clearly show that at least some kind of compression is necessary before a node transmits the recorded sound in order for a realistic WASN to be stable [22]. Since the final outcome of ESOUNDMAPS would be the classification of the recorded sounds and the creation of periodically updated soundmaps [17], the effect of sound compression on possible audio features that could be used during the classification step should be investigated. Motivated by this need, we decided to initially focus on the complexity characteristics of sound.

In this context, the work proposed herein investigates the effect of the compression of audio data on the accuracy of the corresponding entropic/information content of sound, as this is determined by different complexity metrics. This investigation is supported by numerical results for a set of entropic/information metrics, compression methods and raw data sample types. More specifically, *we propose that in a realistic WASN for environmental monitoring it is possible to locally compress audio data at node level prior to network transmission while maintaining the complexity characteristics of the sound signal in terms of preserving the precision of specific entropic/information metrics*. However, this is not possible for all the studied combinations "metric-compression algorithm". This way, some of them can be excluded from a future real-time realization of the WASN, while the best of them may be identified.

In this context, Section 2 briefly discusses the considered WASN architecture, as this provided both the motivation and poses specific restrictions in the compression algorithms and data characteristics considered in our analysis. Section 3 provides a short presentation of the framework of the proposed work describing the methods and the material used, while the numerical results that demonstrate the effects of compression on the complexity of various signals under investigation are given in Section 4. The paper concludes, in Section 5, with remarks on the applications of the proposed method, its advantages and potential limitations.

2. Motivation: a wireless acoustic sensor network system for environmental monitoring

International experience has led to a set of requirements that an environmental monitoring WSN system must meet, including (i) autonomy; meaning that the network must be able to operate during prolonged periods of time (ii) reliability; meaning that the network has to perform predictable operations, and prevent unexpected crashes, while human intervention should be minimal (iii) robustness; meaning that the network should employ techniques such as store-and-forward capabilities in order to deal with poor connectivity issues and (iv) flexibility; meaning that one should be able to quickly add, move, or remove stations at any time depending on the needs of the applications. As the "off the shelf" solutions pose numerous practical limitations, the requirement for the design and development of a custom WSN hardware and a communication protocol is raised. Especially, for a WASN, which collects and transmits mainly audio signals, the design task is particularly challenging, since it has to cope with information load which is orders of magnitude larger compared to WSN with low sampling rate sensor nodes (e.g. temperature or humidity sensors). Therefore, several design parameters have to be taken into account both at the hardware/embedded software and the communications level.

In the following, the specific WASN architecture that has been proposed for the ESOUNDMAPS project as well as the main results of the recently presented [22] simulation-based study on its stability in relation to the active recording time, and the input load per node, resulting from different possible compression rates, are briefly presented to make clear the motivation of this paper.

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