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# Abstract


The growth of the Internet since the last century and the spread of digital-multimedia transfer are useful and convenient for us because it has enabled us to access gigantic shared data. As a consequence, demands for applications such as broadcast monitoring, owner identification, proof of ownership, transaction tracking, tampering detection, copy control, and information carrier for audio signal have increased considerably due to technologies misusage. To answer such demands, audio information hiding has been suggested. There are five requirements for audio information hiding. (1) *Inaudibility*: a property that hidden information does not affect a perceptual quality of host signals. (2) *Robustness*: an ability to extract hidden information correctly when attacks are performed. (3) *Blindness*: a property of extracting hidden information correctly without the original signal. (4) *Confidentiality*: a property of concealing the hidden data. (5) *Capacity*: quantity of hidden information. To meet the first requirement is a real challenge because the human auditory system is very sensitive. When the first and the second are required together, the challenge is tougher because they conflict with each other. Compromising them has proved to be difficult. Actually, not just two, but all requirements conflict with each other.

The aim of this research is to explore audio information hiding that can satisfy all requirements, especially the conflict between inaudibility and robustness. A literature review of various audio-information-hiding techniques has suggested that audio watermarking based on singular value decomposition (SVD) is one of the robust techniques, and the published results are promising. Fundamentally, its robustness is due to the fact that a singular value is invariant under common signal processing. The hidden information is embedded by slightly modifying singular values. However, there are two critical problems. First, the problem about the balance between inaudibility and robustness. All SVD-based schemes treat an audio signal as a meaningless time-series and rely only on a mathematical singular-value-manipulation. They have never taken audio features or human perception into account. Second, when we see them from the acoustic-signal-processing point of view, the physical meaning of singular values has never been addressed. Thus, it seems impossible to formulate a modification rule associating with human perception. The sole philosophy behind the published embedding rules seems to be that, notwithstanding the physical meaning of singular values is unknown, a human being cannot perceive the difference between original and watermarked sounds if the modification is done slightly.

Inspired by these facts, we propose a framework based on the singular-spectrum analysis (SSA), which is closely related to the SVD. We show that, by using SSA, singular values can have the physical meaning. Actually, they are scale factors of oscillatory components of the signal. Hence, by adopting SSA, we can exploit the advantages of SVD-based techniques, and, at the same time, SSA provides us the framework in which a modification rule can be informed. Quite contrary to the philosophy of conventional SVD-based schemes, the philosophy of this work is based on an idea that the embedding rules should be based on both the nature of the audio signal and the human audio-perceptual ability. When combining human perception model, such as the psychoacoustic models, and the strength of the SVD-based technique together, it is expected that the problem of conflicting requirements can be solved. Solving this problem is the ultimate goal.

In this work, we investigate the potentiality of SSA and formulate some basic principles that can be used to achieve the goal. Six audio-information-hiding models based on SSA are proposed. The test results show that the proposed framework achieve five subgoals. The scheme we implement can keep the advantages of the SVD-based technique and, at the same time, can reach a better performance with the help of an artificial intelligence technique. We also found the connection between singular-spectrum index and peak frequency of oscillatory components and used the finding to improve performance further. In addition, the self-synchronization for watermark detection is proposed. To demonstrate that the framework is practicable, we applied it to applications of ownership protection, information carrier, and fragile audio-watermarking.

**Keywords:** audio information hiding, singular-spectrum analysis, differential evolution, psychoacoustic model, self-synchronization