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Automated recovery of damaged audio files using deep neural networks

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ABSTRACT

In this paper, we propose two methods to recover damaged audio files using deep neural networks. The presented audio file recovery methods differ from the conventional file carving-based recovery method because the former restore lost data, which are difficult to recover with the latter method. This research suggests that recovery tasks, which are essential yet very difficult or very time consuming, can be automated with the proposed recovery methods using deep neural networks. We apply feed-forward and Long Short Term Memory neural networks for the tasks. The experimental results show that deep neural networks can distinguish speech signals from non-speech signals, and can also identify the encoding methods of the audio files at the level of bits. This leads to successful recovery of the damaged audio files, which are otherwise difficult to recover using the conventional file-carving-based methods.

Introduction

The past century has shown a wide adoption of audio recording devices, including smartphones. Thus, the providing of audio files as evidence in court settings has become more common. Audio files that are claimed to be legal evidence usually proceed through the conventional validation process, whereby investigators listen to and identify the contents and examine counterfeit audio files to establish a legal case. However, audio files collected through digital devices, such as smartphones, can be deleted owing to malicious purposes or lack of storage in the devices. For the deleted files to qualify as legal evidence, the process of restoring the audio files from storage, where the deletion occurred, and validating the data are required.

In a typical file recovery environment, file carving—a method to restore deleted files in the file system—has been widely adopted and applied (Poisel et al., 2011). However, the file-carving method often results in incomplete recovery of audio files, which are thus unable to be heard. For instance, after an audio file is deleted from a file system and overwriting takes place, the data in the region might not be restored, thus preventing the complete recovery of the file. Moreover, if the damaged block is an essential part in playing the audio file (i.e., headers of audio files), one would be fully unable to play the file on account of the partial yet critical damage. Therefore, to restore the damaged audio files, we should devise a new approach to recovery. Such a recovery method would involve inferring the lost data based on the data that remain in the file. When a file proceeds through a complete recovery process, the process should successfully recover the lost data that the conventional methods cannot restore. The focus of the present research is the application of deep neural networks for automation of the tasks that are vital yet unsuitable to process manually owing to the difficulty level and time required.

The remainder of this paper is organized as follows. Section 2 explains the conventional file carving method. Section 3 outlines the application of deep neural networks to the present objective. Sections 4 and 5 present the experiments and results verifying the accuracy of the proposed deep neural network method, and we conclude the paper in Section 6.

File-carving methods

Most existing file-recovery methods are file-carving-based methods based on the structures and contents of the files deleted from the file system. Fig. 1 illustrates the full recovery process of a

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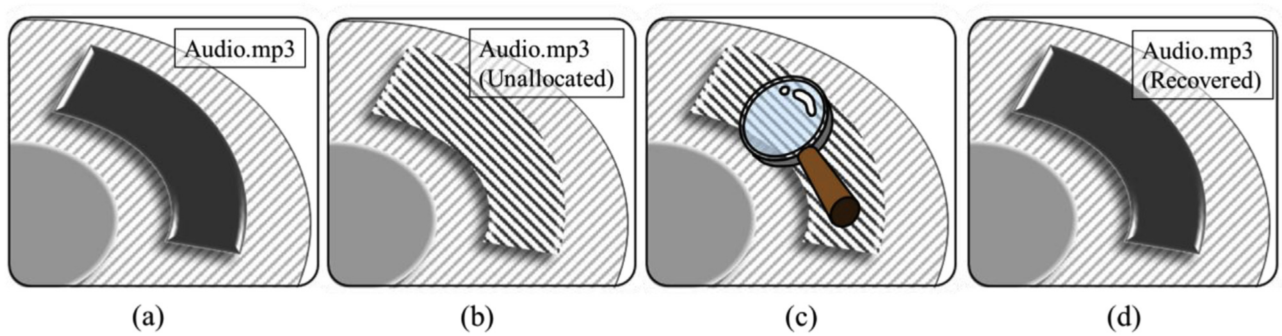

Fig. 1. Flow of file recovery based on file carving. (a) Physical storage and metadata are generated in the file system ("Saving 'Audio.mp3'"). (b) Only the record of the file system is removed; the actual data remain ("Removing 'Audio.mp3'"). (c) Investigating the storage device for file carving. (d) Metadata are re-generated based on the file-carving result.

file-carving method. The file system indicates the complete system that manages all the files employed by users. When a user saves a specific file, the file system generates metadata with information, including the physical location of the saved file and the generated time. It prevents other files from overwriting in the same location, as shown in Fig. 1a.

When a user deletes a file, the file system deletes the previously generated metadata and changes the settings to enable other files to overwrite the location (Fig. 1b). In this case, file carving is the process of reading the deleted files by investigating the saved locations, even when the metadata are not available owing to the deletion of the file by the user (Fig. 1c). Thus, file carving restores access to the deleted files from the file system; it is not an actual method for restoring lost information.

However, a recovery method as such can completely recover files only when the files were not overwritten. For instance, if a WAV type audio file was deleted and WAV header, necessary for playing, was overwritten, it would be difficult to play it back, even when the file was recovered with file carving. Fig. 2 illustrates an example of damaged files in the file-carving process. When a file is damaged or overwritten, it is necessary to use a method that can infer and recover damaged data and thus differs from the conventional method.

Proposed recovery method based on deep neural networks

A WAV file with a corrupted header, which prevents the file from playing, can be fixed with the proposed recovery method to infer damaged information based on data other than the header (i.e., encoded signals). This recovery process is different from that of the existing file-carving method and addresses problems that the existing method cannot solve. Nevertheless, the proposed process requires tasks that are not suitable to perform manually because the tasks are challenging and time-intensive. We therefore automate the tasks based on deep neural networks and accordingly propose two ways to develop new recovery methods.

Inference on header information based on speech or non-speech decision

The following process can recover an audio file with a corrupted header. First, the header information that is expected to exist in the damaged audio file is generated. For example, when bit-rate information must exist in the header of the audio file, the header information for all possible bit rates, which can be used in the audio file, should be generated to be tested. Based on each generated header information, the audio file is decoded and it is determined whether the decoded signals are speech or nonspeech. Herein, speech signals refer to the signals that can be identified to be normal sounds when the header information is properly generated just the same as that before the damage. Nonspeech signals refer to improperly decoded signals whose generated header information is different from the original header information. Proper decoding of a speech signal is not possible unless the header information matches the one in the encoding process. Thus, we have to generate header information arbitrarily until the original speech signals are decoded.

When one can identify normal audio signals in this process, lost header information is assumed to be properly inferred. However, if a person performs the tasks, he or she should repeatedly generate different headers, decode, and listen to the decoded audio for all possible permutations of header parameters. As possible cases would be too numerous for this endeavor, considering the actual encoding methods of audio files, it is not possible to recover all the

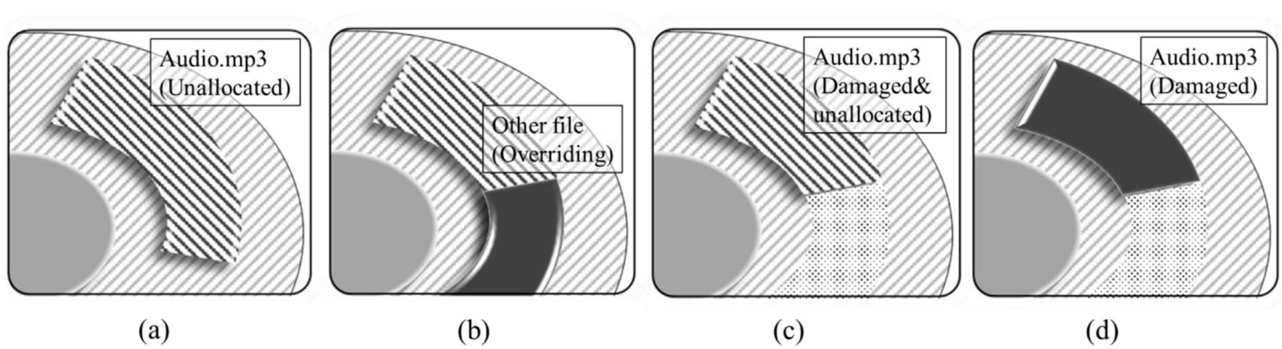

Fig. 2. Example of cases in which it is difficult to recover the file completely by using the conventional file-carving method. (a) Unallocated file before file carving (Fig. 1b). (b) Another file that overrode some part of unallocated file. (c) Damaged and unallocated file because of another file writing. (d)Damaged file after file carving.