Forensic originality identification of iPhone’s voice memos

Jinhua Zeng*, Qiuxiu Lian, Shaopei Shi
Academy of Forensic Science Shanghai, China
*Corresponding author e-mail: zengjh@ssfjd.cn

Abstract. In this paper, we focus on the meta-data analysis methods and digital forensics techniques to solve the problem of forensic originality identification of audio recordings recorded by the Voice Memos App in the iPhone. The Voice Memos App is the built-in application for voice recording and editing in the iPhone. We first introduce the features of the Voice Memos App. Then, the experimental study is carried out to collect and analyze the original and the non-original audio recordings from different iPhones and iOS versions. The file structure pattern, time related file attribute information pattern, application database data pattern of the original audio recordings are analyzed and concluded in this paper, which can be valuable for forensic identification of original audio recordings.

1. Introduction
Audio-visual materials are important forms of legal evidence which are stipulated in the laws and regulations, such as the Criminal Procedure Law and the Civil Procedure Law of China. The audio is an important part of audio-visual materials, the research on the authentication of audio recordings has important value on the theoretical research and practical applications in forensic science.

Audio authentication examination mainly refers to the professional judgment on whether the recordings are post-processed. Its examination methods include auditory testing, sound spectrum analysis, meta-data analysis, statistical analysis of digital data, etc [1].

In practical cases, we often face the cases in which questioned recordings are recorded by using the iPhone. The recordings on the iPhone are often presented in court served as supportive evidence. The expert witnesses have to judge on the authenticity and integrity of the submitted questioned recordings, and have to answer whether or not the questioned recordings are primitive or tampered. Therefore, the research on the techniques of authentication of the iPhone’s recordings has important value.

The research on authentication of the iPhone’s recordings involves the general techniques of audio authentication examination, at the same time, it is closely related to the characteristics of the iPhone and its operating system. Currently, the techniques for authentication examination of iPhone recordings are still unnoticed, which are the aim of this paper.

1.1. The iPhone and iOS
iPhones are lines of smartphones which are designed and marketed by Apple Inc. iPhones use the iOS mobile operating system software developed by Apple. Apple has been amongst the top five smartphone vendors in the world since 2009, and the market share of the iPhone within the smart phone segment in the fourth quarter of 2018 is 18.2%.

The iPhone and its iOS operating system information are shown in Table 1[2].
Table 1. The iPhone and its operating system information

| iPhone version | Initial operating system | Release date | Highest support operating system | Maintenance deadline |
|----------------|--------------------------|--------------|----------------------------------|----------------------|
| iPhone         | iPhone OS 1.0            | 2007/6/29    | iPhone OS 3.1.3                  | 2010/6/20            |
| iPhone 3G      | iPhone OS 2.0            | 2008/7/11    | iOS 4.2.1                        | 2011/3/3             |
| iPhone 3GS     | iPhone OS 3.0            | 2009/6/19    | iOS 6.1.6                        | 2013/9/18            |
| iPhone 4       | iOS 4                    | 2010/6/21    | iOS 7.1.2                        | 2014/9/17            |
| iPhone 4S      | iOS 5                    | 2011/10/14   | iOS 9.3.5                        | 2016/9/12            |
| iPhone 5       | iOS 6                    | 2012/9/21    | iOS 10.3.3                       | 2017/9/18            |
| iPhone 5CS     | iOS 7                    | 2013/9/20    | iOS 10.3.3                       | 2017/9/18            |
| iPhone 5S      | iOS 7                    | 2013/9/20    | latest iOS                       | (current)            |
| iPhone 6/6Plus | iOS 8                    | 2014/9/19    | latest iOS                       | (current)            |
| iPhone 6S/6S + | iOS 9                    | 2015/9/25    | latest iOS                       | (current)            |
| iPhone SE      | iOS 9.3                  | 2016/3/31    | latest iOS                       | (current)            |
| iPhone 7/7Plus | iOS 10                   | 2016/9/16    | latest iOS                       | (current)            |
| iPhone 8/8Plus | iOS 11                   | 2017/9/22    | latest iOS                       | (current)            |
| iPhone X       | iOS 11.0.1               | 2017/11/3    | latest iOS                       | (current)            |
| iPhone XS/XS Max | iOS 12                | 2018/9/21    | latest iOS                       | (current)            |
| iPhone XR      | iOS 12                   | 2018/10/26   | latest iOS                       | (current)            |

1.2. Voice Memos App
The built-in application for audio recording in the iPhone is the Voice Memos App, which is first released in the iPhone OS 3.0. It allows users to record and edit voice memos. Nowadays, the function of the Voice Memos App includes audio recording, recording editing, recording deletion, etc. After users record a voice memo, it’s easy to replace a section, trim the recording, or delete part of it.

The characteristics of the Voice Memo App should be noted in the practical case examination. The features of the Voice Memos App are summarized as follows:

- Users can turn the volume all the way down by using the iPhone volume button while recording.
- Voice Memos will record any sound produced by users and device movement.
- Voice Memos will stop recording if any other Apps play audio in the iPhone, such as playing an incoming call ring tone.

The default recording is mono, but users can record stereo recording by using an external stereo microphone.

2. The techniques for forensic authentication of audio recordings
Forensic audio authentication refers to the professional judgment on the originality, continuity and integrity of questioned recordings by using the methods including auditory testing, sound spectrum analysis, meta-data analysis and digital data analysis [3,4], etc. The originality examination of the recordings is mainly through the meta-data analysis and digital forensics techniques to determine whether the recordings are original or not.

2.1. Meta-data inspection of digital audio recordings
The MPEG-4 standard based digital audio recordings, such as the files with the suffix of “.mp4” and “.m4a”, usually contain meta-data in the files. In the meta-data, we can find the encoded data, tagged data, writing application, etc. One example is shown in Fig. 1. The meta-data examination is an important inspection content and angle for forensic audio authenticity examination.
2.2. Digital forensics examination

Digital forensic examination in the forensic audio authentication application is through the inspection on recording devices related digital data, such as file attribute information inspection of the device file system, the database examination of the recording application, the log information inspection, the file recovery inspection and so on [5,6].

The device related digital information examination can offer important digital footprints if the questioned audio recordings are post-processed manually. Especially, the application database information examination has an important role on authenticating digital audio evidence [7]. The examination contents of the application database are described as follows:

- The file attribute examination of database files, database backup files, log files and other related files;
- The inspection of database tables and their field data;
- Determine whether the database structure and the data are abnormal;
- Find the anomalies in the time sequence of records in the database table;
- Examine whether there are anomalies between the database log file and the current database data;
- Examine whether there are anomalies between the database backup data and the current database data;
- Analyze other data that can verify the data in the database.

3. Experimental Study

The built-in App for audio recording in the iPhone is the Voice Memos. By 2018, the iPhone’s operating system has been updated to the iOS 12. The Voice Memos in different versions have some differences, but are substantially same in application interface, operation method, and data organization structure.

3.1. Used iPhones in the experiment

During the experiment, we use the iTools 4 to acquire the Voice Memos files from 5 iPhones. The information of the used iPhones is shown in table 2.
Table 2. The used iPhones in the experiment

| No. | iPhone version          | operating system |
|-----|------------------------|------------------|
| 1   | iPhone 6 Plus (16GB)   | 8.1              |
| 2   | iPhone 6 (64GB)        | 10.0.1           |
| 3   | iPhone 7 Plus (128GB)  | 12.1.4           |
| 4   | iPhone 8 (64GB)        | 12.1.4           |
| 5   | iPhone XR (128GB)      | 12.2             |

3.2. Experimental design
The experimental steps are designed as follows:
Reboot the iPhone; Use the iTools to save all data of the iPhone’s Voice Memos; Record the file attribute information of the files and folders in the Voice Memos application;
Import three audio recordings into the Voice Memos, labeled as DR1, DR2 and DR3 with duration of 10 seconds, 30 seconds, 3 minutes respectively. The DR1, DR2 and DR3 are recorded by using iPhone 6 with 8.1 iOS. Then perform step a.
Replay the DR1 in the Voice Memos; Click the edit button of the DR2 and play the DR2; Then perform step a.
Record six audio recordings with the duration of 30 seconds, 1 minute, 2 minutes, 3 minutes, 3 minutes respectively, labeled as RC1, RC2, RC3, RC4, RC5, RC6; Then perform step a.
Replay the RC1 in the Voice Memos; Click the edit button of the RC2, and then replay the RC2; Click the edit button of the RC3, trim the RC3, and resave it as the new recording labeled as RC3n; Click the edit button of the RC4, trim the RC4, and resave it by replacing the original RC4; Click the edit button of the RC5, Tap replace button to rerecord over the existing memo, and resave it as the new recording labeled as RC5n; Click the edit button of the RC6, Tap replace button to rerecord over the existing memo, and resave it by replacing the original RC6; Then perform step a.
Delete all the recordings in the Voice Memo; Then perform step a.

4. Experimental results

4.1. Data Organization Structure of the Voice Memos
The default storage path of the Voice Memos is in "/var/mobile/Media/Recordings/", The basic file structure is shown in Fig. 2.

Fig.2 The basic file structure of Voice Memos in the iPhone with iOS 8, iOS 10 (left), and iOS 12 (right).

In the iOS 12 iPhone with iCloud support, the additional files of CloudRecording.db, CloudRecording.db-shm, CloudRecording.db-wal, and folders named as “.Recordings_SUPPORT” and “.CloudRecordings_SUPPORT” are included in the Voice Memos.
The “.plist” file is the property list file, which is a structured text file that contains the application's configuration information and users’ setting. It can be edited by using plist editors. The “.db” files are SQLite database. The DB-SHM file and the DB-WAL file are temporary files of the database. The WAL
files are a form of cache, the data written into the SQLite database are first written into the WAL file, and then written to the main database file at a certain time. So, in order to view the full data, the “.db” and “.db-wal” files need to be in the same directory before opening the “.db” file with a SQLite database viewer.

When recording a voice memo in the iPhone, the application will create an audio file with .m4a suffix, as well as .waveform file and .composition folder with the same name of the audio file.

The “.waveform” file saves the audio waveform graphic data. The composition folder usually contains an “fragments” folder and a manifest.plist file. The manifest.plist file contains the information of the uniform resource locator and the uniform resource identifier of the audio recording.

In the iOS 12, the manifest.plist file additionally contains the field of the creation time information of the audio recording. One example is shown in Fig. 3. And the “.CloudRecordings_SUPPORT” folder contains the audio backup files of the Voice Memos.

4.2. Time related information of audio recordings

When recording an audio, users can name the audio recording, but in the application, the memos are named by using their creation time with the suffix of “.m4a”, that is, the file name indicates the creation time of the audio recording.

The meta-data information of the audio files contain the time related information, such as recording time, duration, encoding time, tagged time, etc. The recording time is the starting time of audio recordings displayed in the time zone set in the iPhones’ iOS. The encoding and tagged times are the last save time of audio recordings, which are displayed in the UTC format. The recording time is included in the audio meta-data in the iOS 8, but not in the iOS 10 or later iOS versions.

In addition, the file attribute information contains the time related information. We can use the iTools to access the last modification time of audio files, and their related files, such as “.m4a” es and their homonym “.waveform” files and “.composition” folders.

4.3. Application database of Voice Memos

The structure of the SQLite database of the Voice Memos in iOS 10 is shown in Fig. 4.
The database contains six database tables. The main information in the database tables is described as follows:

- The Z_meta-data table contains the field of Z UUID, and the UUID is the abbreviation of the universally unique identifier.
- The ZDATABASEPROPERTY table contains the field of ZKEY, which records the next recording number of the Voice Memos.
- The Z_PRIMARYKEY table contains the field of Z_NAME, which records the maximum number of recordings in the Voice Memos ever before;
- The ZENTITYREVISION table contains the field of ZRECORDING_ID which records the serial number of each memo;
- The ZRECORDINGID table contains the fields of ZRECORDINGID, ZDATE, ZDURATION, ZCUSTOMLABEL, and ZPATH. The meanings of the above fields are shown in Table 3.

### Table 3. The fields’ meaning information of the ZRECORDING table

| Field name     | Meaning            | Type       |
|----------------|--------------------|------------|
| ZRECORDINGID   | identity number    | INTEGER    |
| ZDATE          | recording time     | TIMESTAMP  |
| ZDURATION      | duration           | FLOAT      |
| ZCUSTOMLABEL   | user defined name  | VARCHAR    |
| ZPATH          | path               | VARCHAR    |

In the iOS 12, the database structure has great changes comparing with the iOS 10, as shown in Fig. 5. The audio related information is basically located in the “CloudRecordings.db” database. And the recording time, recording duration, and other information are located in the “ZCLOUDRECORDING” table.
5. Forensic Originality identification of audio recordings in the iPhone

The original audio recordings in the iPhone have their own characteristics, including the features in the audio related file structure, time-related information, and database information.

5.1. The file structure pattern of original audio recordings

(1) Besides the questioned audio recording, the Voice Memos contained the waveform file and the composition folder with the same name of the questioned audio file.

(2) There is a manifest.plist file in the .composition folder, in which the audio related information is saved, such as the user defined name, storage path, and even the creation time information in the iOS 12.

These are “.db” database files in the Voice Memos. In the iOS 12 with iCloud support, these is a “.CloudRecordings_SUPPORT” folder, in which the backup file of the questioned audio is preserved.

5.2. Time related information pattern of original audio recordings

(1) The name of the questioned audio file indicates its creation time. In some cases, the audio file name consists of the time information and “-digit.m4a”, such type of file names may indicate they are external imported audio recordings.

(2) In the iOS 12 iPhone, the time revealed in the questioned audio file name must be equal to the creation time contained in the manifest.plist file.

(3) If the questioned audio recording is not been replayed or edited, the last modification time among the “.m4a” file, “. waveform” file, and “. composition” folder are the same. The last modification time can be examined by using iTools software.

(4) The time revealed in the questioned audio file name must be equal to the recording time contained in the meta-data of the audio file.

(5) The last modification time of the audio recording must be identical to the sum of the creation time, duration, and the operation time. The operation time may consist of the pause operation, user naming the audio file operation, edit operation, etc. The audio recording with overlong operation time may indicated the anomaly.

(6) The last modification time of the audio recording must be equal to the encoding time or tagged time in the meta-data of the audio file.

In the above equation, there may be several seconds error because of the truncation calculation of floating-point number in the system.

5.3. Database data pattern of original audio recordings

(1) The database must contained the records of the questioned audio recordings.
(2) In the iOS 10 iPhone, the creation time and duration of the questioned audios in the ZRECORDING table must be consistent with the time related information pattern as mentioned in the section 5.2.

(3) The default numerical type of the ZDATE field in the ZRECORDING table is floating-point number.

(4) In the iOS 12 iPhone, the creation time and duration of the questioned audios in the ZCLOUDRECORDING table must be consistent with the time related information pattern as mentioned in the section 5.2.

6. Conclusion
With regard to the problem of forensic originality identification of audio recordings in the iPhone, we focus on the meta-data analysis method and digital forensics techniques to answer this question. Through the experimental study, we collect the Voice Memos data from different iOS versions and iPhones. We find that the original audio recordings have specific patterns on the file structure, time related file attribute information, application database data. We analyze and conclude the Relevant patterns which can be valuable for forensic originality identification of audio recordings recorded by the Voice Memos App in the iPhone.

Acknowledgments
This work is supported by Shanghai Sailing Program (17YF1420000), Shanghai Minsheng Science and Technology Support Program (17DZ1205500), and Ministry of Finance, PR China (GY2018G-6).

References
[1] S. Shi, X. Yang, W. Sun, X. Bian, X. Chen, J. Xi, C. Xu, H. Qian, “General specification for forensic audio and video examination (No. SF/Z JD0300001-2010),” Ministry of Justice, China. 2010.
[2] “IPhone,” https://en.wikipedia.org/wiki/IPhone, 2019.
[3] S. Gupta, S. Cho and C. C. J. Kuo, “Current developments and future trends in audio authentication,” IEEE MultiMedia, vol. 19, no. 1, pp. 50-59, 2012.
[4] M. Zakariah, M. K. Khan, H. Malik, “Digital multimedia audio forensics: past, present and future,” Multimedia Tools and Applications, vol. 77, no. 1, pp. 1009-1040, 2018.
[5] W. H. Allen, “Computer forensics,” IEEE Security & Privacy, vol. 3, no. 4, pp. 59-62, 2005.
[6] S. L. Garfinkel, “Digital forensics research: The next 10 years,” Digital Investigation, Vol. 7, pp. S64-S73, 2010.
[7] Y. Li, S. Shi, X. Yang, Q. Lu, J. Zeng, X. Bian, X. Chen, W. Qiu, Z. Huang, C. Xie, “Specification for forensic authentication of database data (No. SF/Z JD0402002-2015),” Ministry of Justice, China. 2015.