# A Shazam-like Household Water Leakage Detection Method

Seyoum, Solomon; Alfonso, Leonardo; Andel, Schalk Jan Van; Koole, Wouter; Groenewegen, Ad; Van De Giesen, Nick

**DOI**
10.1016/j.proeng.2017.03.253

**Publication date**
2017

**Document Version**
Final published version

**Published in**
Procedia Engineering

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 186 (2017) 452 – 459

Procedia Engineering

www.elsevier.com/locate/procedia

XVIII International Conference on Water Distribution Systems Analysis, WDSA2016

# A Shazam-like household water leakage detection method

Solomon Seyoum[a], Leonardo Alfonso[a]*, Schalk Jan van Andel[a], Wouter Koole[b], Ad Groenewegen[b], Nick van de Giesen[b]

*[a] UNESCO-IHE, Intergated Water Systems and Governance Department, 2611AX, Delft, The Netherlands*
*TU Delft , Civil Engineering & Geosciences, 2628 CN Delft, 2600GA Delft, The Netherlands*

**Abstract**

Waternomics is a European Union-funded research project aspiring to develop and introduce Information and Communication Technology (ICT) as an enabling technology to manage water as a resource, increase end-user conservation awareness, affect behavioural changes and avoid water losses through leak detection. Existing leakage detection methods are generally focused on scrutinising large diameter pipes in water supply distribution networks or transmission pipes. However, it has been estimated that the average household's leaks can be as much as 35$m^3$ of water per year. In order to solve the problem, analysis of different types of data in the household piping system is required, including detection and identification. One conventional approach is to use flow sensors installed at several locations within the household piping system and perform a mass balance approach to detect leakage. However, this method is expensive and difficult to implement.

This research proposes a novel approach to household leakage detection by means of sound signal recordings. The approach consists of recording the sound signals that are produced by water fixtures and appliances, and then use these recordings to detect any abnormal situation which may be an indication of a leak. The method comprises three major steps: recording, storing and processing of sound signals. The recording step is done by means of a non-intrusive sound sensor that sends records remotely; the storage step is made in a database of sound signals for different types of uses; finally, the processing step is made through a sound signal identification software tool that is able to search the database libraries for related sounds, in a similar way as the Shazam app for music. Tests of the leak detection method are presented for data collected in laboratory conditions. Results show that this detection method has a potential to help reducing leakages through an easy-to-install and non-intrusive sensor.

* Corresponding author. Tel.: +31 6 48674148;
*E-mail address:* l.alfonso@unesco-ihe.org


Peer-review under responsibility of the organizing committee of the XVIII International Conference on Water Distribution Systems
doi:10.1016/j.proeng.2017.03.253

Peer-review under responsibility of the organizing committee of the XVIII International Conference on Water Distribution Systems

*Keywords*: Leak detection; sound signals; sensor

## 1. Introduction

Although household water consumption can increase substantially due to leakage, small and medium sized leaks in household plumbing are generally ignored. The leaks may be undetected below ground, through dripping taps and toilet cisterns. When considered individually, leaks may seem insignificant; however, taken collectively over a long period they result in a major loss of water. [1] reported that the rate of water loss could vary depending on the type and severity of the leak. Generally, dripping taps can lose between 3-30 litres per day, leakage from toilet cisterns can range from 10 litres per day for invisible leaks to 340 litres per day or more for leaks large enough to be see and/or have an audible refilling sound. Mayer, et al. [2] found out in their Residential End Uses of Water Study that leak constitute 13.7% of the indoor per capita consumption of a single residential house in North America. Therefore, identifying internal leak enable customers to fix the problem, saving water and money.

Detecting and identifying leakage in the household levels requires the analysis of different type of censored data in the household piping system. One of the traditional approaches is to use flow sensors and perform a mass balance approach to detect leakage. . Researchers in Australia use automated meter reading technology to identify household water leakage in residential properties located within a selected district metered area [1]. Another novel approach could be to use sounds recording to detect leakage. There exist several techniques for leak detection, which concentrate generally on finding leaks in main pipes. However, many leaks at the domestic level contribute significantly to unaccounted-for water in many water distribution networks. In general, these leaks are minor but numerous and they go unnoticed by conventional monitoring techniques.

Leakage Management comprises four main components [3] quantifying water loss, 2) leakage monitoring, 3) network pressure and asset management and 4) leak detection, location, and repair. While 1) and 2) are activities that aim at quantifying and measuring the amount of water that is lost in an area of the distribution network, the leak detection is an active effort to pinpointing the exact position of a leak. Due to the fact that these activities are costly, water utilities concentrate on reducing water losses by detecting and locating leaks generally in the main pipes of the distribution network. For this reason, the development of sensor devices has been concentrated almost exclusively on professional monitoring of big diameters by a range of different equipment that mainly based on acoustic principles, such as listening devices, noise loggers, and leak noise correlators [4]. Recent advances of these devices address problems such as user bias (e.g., [5, 6]), uncertainty reduction by considering multiparameter measurements such as flow, pressure, and noise [7] and even vibration [8] and active pipe inspection via wireless technologies with video cameras, microphones, acoustic sensors, and smart balls in large-diameter pipes ([9-11]).

Leak detection methods are broadly classified in terms of internal and external monitoring methods: internal methods involving intrusive measurements to monitor fluid state, and externa1 methods applied to the environmental condition of a pipe [12]. Pipelines are designed and engineered for full load operations assuming steady state flow conditions. Operational parameters will range from maximum allowable operating pressure in exceptional circumstances to a depressurized state corresponding to a no-flow situation. Normal pipeline operations may involve day-to-day transients such as pump start/stop operations, the operation of control valuing and changes in delivery rates. Internal leak detection system must therefore operate over wide range of process conditions, some of which may appear to have the characteristic of leak patterns.

We propose an innovative leak detection method for households, which comprises hardware and software advances: a new low cost acoustic sensor and a Shazam-like detection algorithm. The idea is that during the night, the sound in the pipes inside households is listened to with the new sensor, when the background noise is low and the pressure in the system is high, and then analysed with the new algorithm in order to get leakage reports. In this paper we focus on the software side, which is similar to the well-known Shazam mobile application, useful to identify song names and artists from a limited piece of song in noisy environments.

### *1.1. Leakage detection using sound recordings*

Recent developments in the field of computational intelligence (sometimes termed soft computing or machine learning) are helping to solve various problems in the water resources domain. A number of approaches from the fields of artificial intelligence and statistics have been applied for detecting abnormality in water distribution systems from time series data. Alert systems that convert flow and pressure sensor data into usable information in the form of timely alerts (event detection systems) have been developed with a focus on burst detection to help with the issue of leakage reduction [13]. [14] explore data processing and anomaly detection techniques for data from Water Distribution Systems including control charting, time series analysis, Kriging techniques and Kalman filter techniques. They concluded that no single methodology could be judged to always be the best choice. These type of even detection systems have two steps of analysis in common; learn from training data to make a prediction about expected future event and some type of methodology or rules for deciding when sufficient deviation from normality constitute abnormality.

In diagnosis and fault detection applications a pattern database may be query in real-time to determine what past situations (contexts) are most similar to the current sensor profile. As well as detecting that data are abnormal, it is also useful to be able to determine in what way the data are abnormal and ideally to be able to classify the event type which the data correspond to.

Household water fixtures and appliances produce sound signals when in use. Recording, pre-processing and creating libraries of sound signals generated from household water fixtures will help to distinguish between normal operational conditions and abnormal conditions that would indicate a leak. Sound sensors are relatively cheap and easy to install than flow and pressure sensors. Using sound sensors, it is possible to generate time series data which can be analysed to generate useful information to detect leakage. This requires a mechanism to analyse and recognize audio data collected using sound sensors. One of the methods used to identify patterns in audio signals (time series) is audio fingerprinting.

### *1.2. Audio fingerprinting*

An audio fingerprint is a condensed digital summary, deterministically generated from an audio signal that can be used to identify an audio sample or quickly locate similar items in an audio database. Audio fingerprinting systems identify musical content in audio and search a reference database for recordings that contain the same musical features. It is used to take a short sample of an unknown audio recording and retrieve metadata about the recording. It does this by converting the data-rich audio signal into a series of short numerical values (or hashes ) that aim to uniquely identify a musical recording. Audio fingerprinting uses lower-level spectral information in a signal to generate a unique identifier of the audio.

An audio fingerprinting system should be able to recognise audio signals in the same way that a person can. If a person can recognise a song from a short clip of audio then an ideal computer system should also be able to recognise the song. To be able to do this an audio fingerprinting system should utilise the perceptual aspects of the audio contained in the file and not just the way that the file itself is encoded digitally. These so-called content-based identification systems (CBIDs) are named as such because they identify matches based on the musical content of the recordings in the corpus rather than the way that the file is stored by the computer. Furthermore, because humans are able to recognise a recording as being the same even in the presence of small changes to the query, such as tempo variations or noise, effective fingerprinting algorithms should also be able to correctly identify queries that have been modified in similar ways [15].

Most audio-fingerprint systems divide an audio signal into a series of frames. They then use some form of a fast Fourier transform algorithm to track changes in the semantic and non-semantic features of the audio signal. Finally, a classification algorithm examines each frame and organizes them into sub-fingerprints. The basic unit that contains enough data to identify an audio clip consists of a series of sub-fingerprints and is known as a fingerprint block. These audio fingerprints are then stored in a database [16]. The most common sequence of steps employed by most audio fingerprinting systems include pre-processing, framing and overlap, transform and analysis, feature extraction, and fingerprint generation.

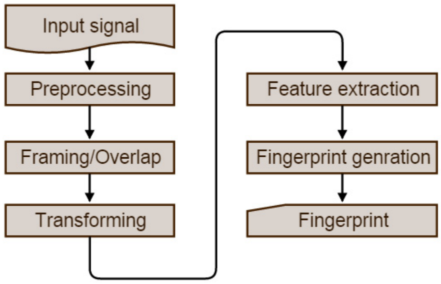


Fig. 1. Steps in Audio Fingerprinting algorithms

The pre-processing step converts all input signals into a common format for analysis by the algorithm. Often, this step involves converting the input to a mono signal and lowering the sampling rate of the audio signal to get rid of information which is not relevant from the human perceptual point of view and to focus on important features of the signal. Next, an algorithm takes the time-series audio signal and converts it into a frequency-domain signal from which more information can be extracted. Framing and overlap determines how many samples to consider when calculating a transform of a time-domain signal. Each frame has a window applied to it to assist in calculations, and the frames are processed in overlapping chunks from the time-series signal. The feature extraction process takes the signal that has been converted into the frequency domain and selects salient features that are used to characterise the audio. Finally, once the features have been chosen and extracted from the signal they need to be converted into a fingerprint representation that can be stored in a database and compared to unknown query signals. Once the fingerprint has been generated, it must be stored in a reference database.

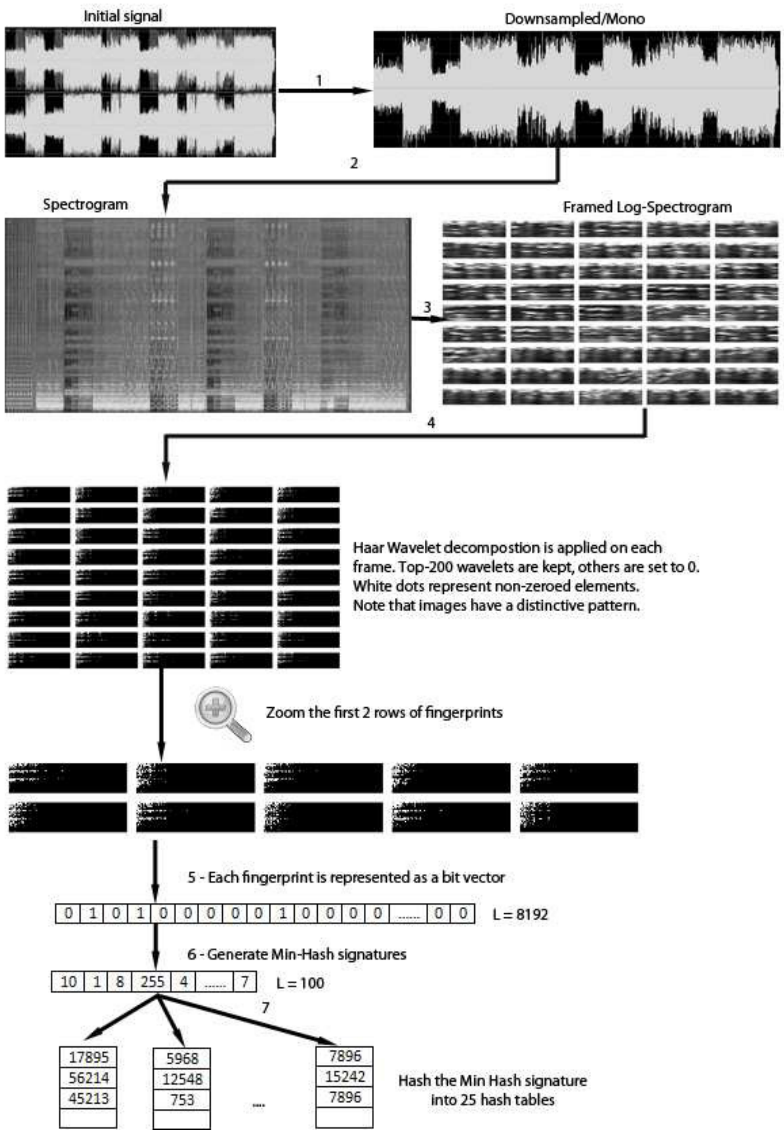


Fig. 2. Sound Fingerprinting Framework (source [17])

## 2. Methodolgy

The methodology consists of populating a database of sounds collected in a lab and in a household with new, low cost sensors and to analyse them with sound fingerprinting software. The lab setup consist of 10 copper and flexible PVC pipes of diameters ranging from 10mm to 22mm. Two low cost sensors at locations A and B were installed (leaks of various discharges were induced and recorded at location A and signals were recorded at several distant locations B). In the household, a low cost sensor was installed between the meter and the first internal ramification of the water network. In all cases, recordings were transmitted through Internet via a wired connection to an online server. The Acoustic Leak Detection (ALD) software works in two modes: Feed mode, in which the software creates fingerprints of each sound recording and build a database; and the Detection mode, in which, once the database is complete, the ALD software works like the Shazam app[†]: listen to new recordings, check if they exist in the database and retrieve the message found / not found. If not found, an abnormal situation is likely to be occurring, e.g., a leak. A flowchart of this process is shown in Figure 3.

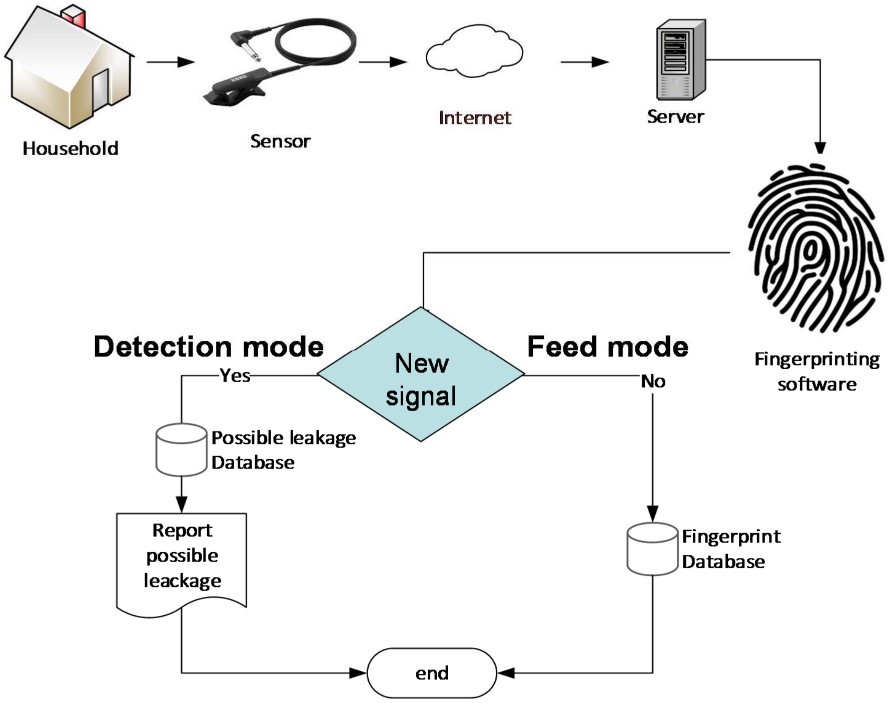


Fig 3. General approach for household leak detection using fingerprinting signals

## 3. Results

The process has been tested with data collected in a lab facility, from which signals such as those presented in Figure 4 were obtained. Audio signals are collected for different simulated leak conditions in different pipe materials and sizes which are normally obtained in household water supply piping systems.

More than 800 recordings in the lab show that for the case of Pexfit pipes the signals increase as pipe diameter increases, and this is the opposite for Copper pipes. Also, that visual differences of sound signals in spectrograms between medium and low leakages are very small. However, these differences can be recognised by the fingerprinting software.

Some of files are not correctly identified. However, the rate of identification increases as the database is populated with more leak audio signals.

† Copyright Shazam Entertainment Limited. More info: www.shazam.com

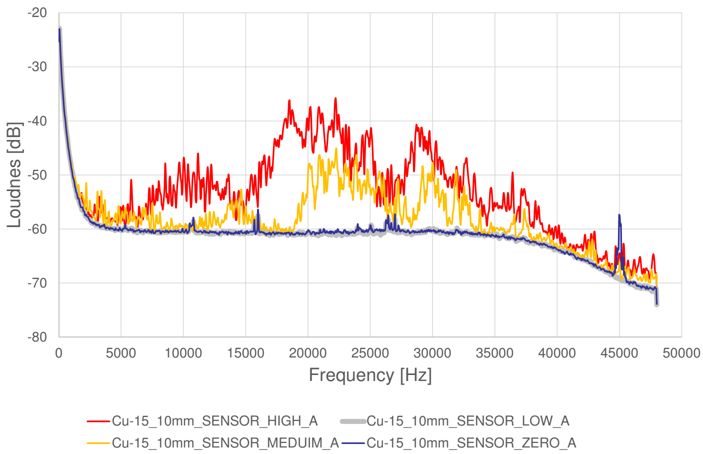


Fig. 4. Examples of spectrograms obtained at the lab for different leakage scenarios, with varying material and diameter.

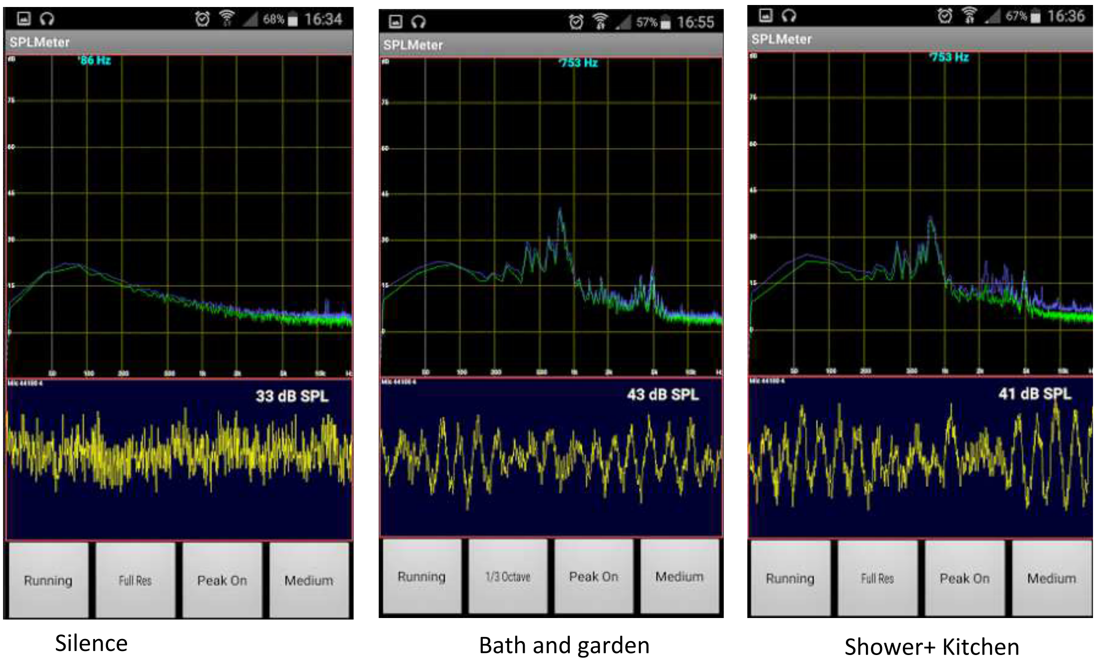


Fig. 5. Examples of spectrograms obtained with the SPLMeter App (Bofinit Corp) at the household for different working water appliances combinations.

## 4. Conclusions

An automatic leak detection method for households has been developed with both hardware (sensor) and software (fingerprinting).The concept of detecting leakage at households via acoustic sensor and a fingerprinting software for signal recognition is sound and promising. Fingerprinting detection was found not sensitive to the degree of opening of faucets / showers, which means that the method can be explored to profile water use patterns of different devices. The method can also be used to complement traditional water balance methods for household leakage detection, as it can automatically establish when water is not being used. A current disadvantage of the method is that the fingerprinting database must be built every time the sensor is installed in a new household, because different network configurations lead to different fingerprinting signals. Next steps in this research include testing different sensors that are being produced and tested in the lab. Moreover, investigate the sensitivity of audio fingerprinting parameters, such as the max and min strides related to sampling rates, the number of tables in the database to save the fingerprinting APIs and the number of wavelet divisions.

## References

[1] T. Britton, G. Cole, R. Stewart, and D. Wiskar, "Remote diagnosis of leakage in residential households," Journal of Australian Water Association, vol. 35, pp. 89-93, 2008.
[2] P. W. Mayer, W. B. DeOreo, E. M. Opitz, J. C. Kiefer, W. Y. Davis, B. Dziegielewski, et al., Residential end uses of water: AWWA Research Foundation and American Water Works Association Denver, CO, 1999.
[3] H. E. Mutikanga, S. K. Sharma, and K. Vairavamoorthy, "Methods and tools for managing losses in water distribution systems," Journal of Water Resources Planning and Management, vol. 139, pp. 166-174, 2012.
[4] D. Hartley, "Acoustics paper," in Proc. of 5th IWA Water Loss Reduction Specialist Conference, Hague, The Netherlands, 2009, pp. 115-123.
[5] A. Clark, "Increasing efficiency with permanent leakage monitoring," in Water Loss Reduction-Proceedings of the 7th IWA Specialist Conference, 2012, pp. 26-29.
[6] S. Hamilton and C. Jones, "Technology—How Far Can We Go?," in Pipelines 2012@ sInnovations in Design, Construction, Operations, and Maintenance, Doing More with Less, 2012, pp. 523-530.
[7] J. Koelbl, D. Martinek, P. Martinek, C. Wallinger, D. Fuchs-Hanusch, H. Zangl, et al., "Multiparameter measurements for network monitoring and leak localising," in Proc., 5th IWA Water Loss Reduction Specialist Conf., Cape Town, South Africa, 2009, pp. 620-627.
[8] G. P. Hancke and G. P. Hancke Jr, "The role of advanced sensing in smart cities," Sensors, vol. 13, pp. 393-425, 2012.
[9] A. Ong and M. Rodil, "Trunk mains leak detection in Manila's West Zone," in Water Loss Reduction–Proceedings of the 7th IWA Specialist Conference, 2012.
[10] C. Stringer, R. Payton, M. Larsen, K. Laven, and D. Roy, "Integrated leak detection at Dallas Water utilities," in Pipelines 2007@ sAdvances and Experiences with Trenchless Pipeline Projects, 2007, pp. 1-6.
[11] Z. Y. Wu, Water loss reduction: Bentley Institute Press, 2011.
[12] R. S. Stafford and D. E. Singer, "National patterns of warfarin use in atrial fibrillation," Archives of internal medicine, vol. 156, pp. 2537-41, 1996.
[13] S. Mounce, R. Mounce, T. Jackson, J. Austin, and J. Boxall, "Pattern matching and associative artificial neural networks for water distribution system time series data analysis," Journal of Hydroinformatics, vol. 16, pp. 617-632, 2014.
[14] R. Jarrett, G. Robinson, and R. O'Halloran, "On-line monitoring of water distribution systems: Data processing and anomaly detection," in Proceedings of the 8th Water Distribution System Analysis Symposium, 2006, pp. 27-30.
[15] A. Porter, "Evaluating musical fingerprinting systems," McGill University, 2012.
[16] M. Brown. White Paper: Audio Fingerprinting. Available: http://www.maximumpc.com/article/features/white_paper_audio_fingerprinting
[17] C. Sergiu. (2013, January). Duplicate songs detector via audio fingerprinting. Available: http://www.codeproject.com/Articles/206507/Duplicates-detector-via-audio-fingerprinting