Demo of the TimbreID-VST Plugin for Embedded Real-Time Classification of Individual Musical Instruments Timbres

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***Abstract*—This demo presents the timbreID-VST plugin, an audio plugin in Virtual Studio Technology format dedicated to the embedded real-time classification of individual musical instruments timbres. The plugin was created by porting the code of the timbreID library, a collection of objects for the real-time programming language Pure Data that allows the real-time classification of features of audio signals. The JUCE framework and the building tools provided by the Elk Audio OS operating system were utilized, which allows the plugin to be used in the embedded systems supported by Elk Audio OS. The availability of the timbreID-VST plugin utilities as a library facilitates the development of intelligent applications for embedded audio, such as smart musical instruments. The plugin was trained to classify percussive timbres from an acoustic guitar.**

I. Introduction

Recently, a family of musical instruments featuring advanced context-aware and proactive capabilities has been proposed, the so-called smart musical instruments [1]. At hardware level, smart musical instruments are characterized by sensors, embedded systems, and wireless connectivity. Existing instances of such kind of Musical Things are the Sensus Smart Guitar developed by Elk [2] or the Smart Cajón reported in [3].

The development of this class of intelligent instruments requires embedded technologies dedicated to real-time audio tasks. In recent years various platforms targeting this purpose have appeared both as commercial or open source projects [4]. To date, the two most prominent platforms supporting the creation of smart musical instruments are: i) the Bela Board, which is based on Linux Xenomai and the Beagle Bone Black single board computer (www.bela.io); ii) the Elk Audio OS, an operating system also based on Linux Xenomai and that supports a variety of single board computers (www.elk.audio). Elk Audio OS is based on a sound engine that supports commercial and non-commercial audio plugins in various formats (e.g., LV2, VST, RE). A peculiarity of the operating system is the capability of ensuring low-latency processing and high sound quality while at the same time supporting advanced networking options. Given these features, Elk Audio OS can be considered the most advanced platform for the creation of smart musical instruments.

Several of the intelligent applications envisioned for smart musical instruments are based on the understanding, in real-time, of what is being played (e.g., the performative gestures of the player). This requires efficient algorithms for the real-time classification of properties of the audio signal generated by a player, such as the timbre. Various methods have been developed in the field of Music Information Retrieval [5] for the classification of audio signals, nevertheless relatively little research has been conducted in the real-time domain.

A prominent tool for real-time classification of features of audio signals is *timbreID* [6]. This is a collection of objects for the real-time programming language Pure Data (www.puredata.info), which is freely available (https://github.com/wbrent/timbreID) and particularly useful for the classification of timbres of individual musical instruments. The timbreID library - besides providing efficient implementations of a set of low-level temporal, spectral, and cepstral feature-extraction techniques - also integrates a real-time classifier based on the K-nearest neighbors algorithm, which takes in input vectors of extracted audio features. The library was utilized for the creation of the Smart Cajón reported in [3].

For this demo we ported the timbreID library from the Pure Data external format to C++ for the JUCE framework and the building tools of Elk Audio OS were used to produce a plugin that can run on the platforms supported by said OS. JUCE was chosen because it allows compile code in the Virtual Studio Technology (VST) plugin format, and particular attention has been devoted to coding a fully headless plugin (i.e., without a graphical user interface).

Pure Data objects of *timbreID* are originally coded in C language with use of utilities from the Pd library for externals: custom data types and utilities were substituted with JUCE structures and functions, while the rest of the code was adapted to C++14.

II. Evaluation

The functionalities of the library were tested on a real world problem: the classification of percussive timbres produced by hitting the body of an acoustic guitar.

The percussive technique is very popular among modern acoustic guitar players and the interaction with some of them, along with previous research [7] helped to identify 4 main

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timbres produced on different areas of the guitar. The timbres selected are the following:

1) Palm on lower guitar body
2) Fingers on lower side
3) Thumb on top guitar body
4) Fingers on the keyboard (muted strings)

All the experiments were performed using a training dataset of 390 audio samples (~100 per timbre) and a test dataset composed of 80 samples. All of the recordings were performed on a Yamaha APX-8A acoustic guitar using the internal piezoelectric transducers and pre-amplifier. Note this standard setup is not ideal for all kind of sounds; as a matter of fact more modern amplification systems integrate a condenser microphone and/or a magnetic pickup.

Two studies (`study-1`, `study-2`) were carried out to compare the performance of the original K-nearest-neighbors classifier from timbreID and a feed forward neural network.

The configuration for `study-1` uses the Bark onset detector chained to the BFCC feature extractor and finally to the Knn classifier (timbreID object), k = 3.

The configuration for `study-2` is identical except for the classifier that is now replaced by a feed forward neural network, composed by an input layer of 25 neurons, 2 hidden layers of 25 neurons each and an output layer of 4 neurons. Sparse Categorical Crossentropy is the loss function of choice and the optimizer used was Adam. The number of training epochs ranges from 150 to 600 epochs depending on the test case. For both studies the sample rate is 48000Hz, Bark and Bfcc use a window size of 1024 samples and spacing of 0.5 barks. This produces a vector of 50 coefficients that is reduced by retaining only the first 25 values. The hop size for Bark is 128 samples.

Both experiments were repeated by introducing a delay between the onset detection and the feature extraction, in order to capture a different part of each sound. This should reduce pre-onset resonance and general noise in the extracted values. Given that "the time between an instrument onset and its attack peak varies unpredictably according to the instrument" [8], different delay values have been tested: Bark already introduces a delay of at least 5.33ms (sample rate: 48000Hz) and the 2 values tested for the total delay were 20ms and 10ms, meaning respectively additional delays of 14.66ms and 4.66ms. Given the results, an additional test was run with the `study-1` configuration, without reducing the feature vector.

III. Results

TABLE I. `study-1` scores (KNN)

A-Delay	0ms	4.66ms	14.66ms
Study-1 Accuracy:	0.8125	0.8250	**0.4625**
Study-2 Accuracy:	**0.9250**	**0.9000**	0.4125

From the results in tables I the Neural Network architecture shows to be the clear winner in terms of performance: this is in all likelihood due to the ability of a network of neurons to learn weights for the input features, while K-nearest-neighbors is limited to equal weighting or human designed weights.

Studies using *20ms* total delay showed a great reduction in accuracy while *10ms* results were closer to the score of the setup without delay. More tests need to be done with this parameter, in particular in the real application with a guitar connected to the recognition system: this should prove to work better in that case, even with similar accuracy in the test, because rapid successions of different sounds cause interference between said sounds.

This pilot study used only the *bfcc* feature extractor as previous studies showed that it is more fitting for percussive sounds than other modules offered by the library [8], but more experiments will be carried out with more extractors. The additional test carried out on a smaller dataset with the full 50 values vector computed by *bfcc* was evaluated with a Principal Component Analysis plot (Fig. 1) and compared to the PCA plot of the dataset for the other studies: the greater number of feature show marginally better separation. This, along other configurations will be tested.

Every configuration was successfully compiled as a headless plugin for Elk Audio OS and tested with a guitar.

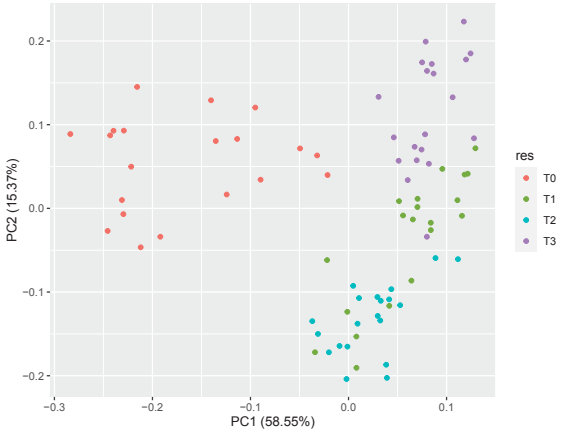

Fig. 1. PCA, 50 features, 20 samples per class. T0:Palm on lower body, T1:Fingers on lower side, T2:Thumb on top body, T3:Fingers on keyboard

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