# DESIGN AND IMPLEMENTATION OF A SOFTWARE FOR THE TRAINING AND REAL-TIME ASSESSMENT OF MUSICAL INTONATION AT MUSIC EDUCATION INSTITUTIONS

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## Abstract

The development of musical intonation is one of the most difficult and complex tasks of music training. Learning tonal melodic patterns is usually done by imitative processes, that is, first by listening to a model composed of pitched sounds and then by performing it. After doing this, pitch sounds are named by means of some syllabic system like the Guidonian or by means of an arbitrary single syllable. Few advances have been made in this area, aside from use of audio supported guides and some computer programs. Some software, such as Ear Master School and Auralia, uses a microphone whose audio information input is analysed by an algorithm that searches sound frequencies. These programs, however, lack the necessary analytical resolution of algorithms or do not have adequate filters of ambient sounds, resulting in a high error rate in the assessment of student responses. The ongoing research discussed here describes the design and implementation of CANTUS, a software program in HTML5 designed for both learning and real-time assessment of vocal intonation, with and without graphical representations. The aim of this software is to serve as a tool for teachers evaluating and diagnosing issues related to the intonation of tonal patterns by students at conservatories and other music education institutions.

CANTUS incorporates the latest research on the use of immediate feedback, both real-time and delayed. The tonal patterns included are composed of up to eight sounds and are designed according to different theories of music learning. There are five working units according to the mode employed: Major, Dorian, Aeolian, Mixolydian, and minor with raised seventh. Also included are patterns with sounds out of the tonality. Execution speed is programmable and includes pitch but not rhythms. Cantus program allows the teacher both to record patterns and to embed them into the program. The evaluation system makes tracking progress possible by means of individual statistics and can also perform an assessment of the ability to read music without sonic imitation. The results can be stored in various media (cloud, email) or printed as pdf. CANTUS can be used on all computer platforms.

Keywords: music technology, musical intonation, sight-singing, music education.

## 1 INTRODUCTION

### 1.1 Musical intonation teaching and learning

The imitation of models or *modelling* has been widely used in all areas of music teaching. In this case, the imitation of melodic patterns has also been a subject of intensive research [15] [17] [31] [33] [44].

The recording models to reproduce or imitate them has also frequently been a subject of study [1] [13] [18] [22] [28]. However, most of these recent studies have addressed musical reading for instruments other than the voice. To support modelling in teaching intonation, a recent study suggests that modelling the singing voice through sung examples is more effective than explaining the performance to a choral group [24].

Sloboda proposes modelling through three stages of learning: *listening, imitation, and extensive practice* [30]. This proposal is based on the cognitive model of Bandura [4]. As will seen later, the technology allows us to combine these three components, providing models to listen to and imitate. Technology could facilitate learner's autonomy in order to find and recognize their pace of practice, with tools like instant vocal feedback and progressive improvement in the assessment of the programmed music reading exercises.


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In a review of studies on the relationship between perception and production in intonation it is suggested that there are no convergent results [10]. However, recent research seems to support the existence of this relationship [41]. One of the factors of influence is the timbre; musical samples with similar timbres seem to improve the accuracy in imitation in the process of perception and production. Regarding the models to imitate, performance is greatest when the vocal model is similar to the learners vocal rage, male or female model / child [9] [49] [47].

## 1.2 Music reading teaching and learning

There are few theories focusing specifically on the music reading teaching and learning process, hence this area of study is not based in a strong theoretical foundation [26]. In a study by Daniels [6] no significant effects were found in the methods and materials used as predictors of accuracy in reading music. Different studies have suggested that intonation reading and rhythmic reading could be dissociated [2] [11] [39]. Gordon in his *Music Learning Theory* proposes the separate study of the rhythmic and melodic elements, although overall no reading music theory is presented. The first step of his theory is imitative process through modelling. [16]

In CANTUS, it is proposed that the intonation of Western musical notation is performed using patterns between 2 and 8 notes, with no duration and accent (notes of the same length). Although in music the three key parameters are combined: melody, harmony and rhythm, these are processed separately [5] [32] [35]. Significant is the affirmation regarding the methods of Western musical notation reading "... we are still striving to find efficient ways to help students learn to read music" [20]. On this issue, there are researches on the relationship between success in musical sight-singing and other variables, such as saccadic eye movement [15] [25] mental images and the degree of cerebral specialization in rhythmic reading and intonation [13] but the conclusions of these studies have not provided much knowledge about the processes of reading music.

Another interesting aspect to investigate is the harmonic contextualization, it seems to facilitate individual accuracy in sight-singing in college students, although it is not clear that the same applies to young students or beginners [20]. Lucas [27] investigated the effect of harmonic context on individual sight-singing. The participants were high school students assigned to three different types of exercise: only melody, piano, and vocal harmony. It is suggested that the use of harmonic context to support sight- singing is less effective in situations of training and practice than in performance situations. This finding contrasts with an earlier study with college students whose performance suggest that the harmonic context improves the accuracy of sight-singing, especially among less experienced students [28]. In any case, Gordon’s theories on the melodic contextualization deserve credit, since music is rarely monodic and needs the listening of harmonic tonal context and functions. For example, it is not the same to sing a C in C major, as it is to sing a C in D major, since in the first case the C is tonic and in the second case it is dominant seventh, merely a rest or a tension to solve. The sounds are not isolated entities, they are cells of a melodic-harmonic tissue and should not be studied in isolation [3].

Meanwhile, Cassidy [6] suggests that the use of syllables or mnemonic devices is an effective strategy to develop reading skills teaching Western musical notation. In general, the solmisation is effective, but the most effective method is yet to be determined [20]. As we will see, Cantus includes two types of solmisation syllables (Latin name of the notes) and a syllable which is neutral regardless of the situation of the note on the staff ("nu").

## 1.3 Pattern Recognition

Music reading requires the perception of sound patterns rather than individual sounds, or interval sounds [18.] The number of sounds that can be memorized by an individual when reading music has been studied by Sloboda, and was fixed in about 7 ± 2 sounds [30]. Since CANTUS develops melodies that can be contextualized with a single chord, a maximum of 8 melodic sounds in each pattern seems sufficient. These have been confirmed for singers [12].

Gordon [16] suggests that the tonal melodic patterns do not have to come directly from the songs that the children are learning, but they must be of the same level of difficulty of the former. In the patterns used for training sequences in learning, this author [16] relies on harmonic functions and thus the patterns are often presented as chord arpeggio melodies.

## 1.4 Teaching sequence

It was investigated the degree of difficulty of the vocal reproduction of tonal patterns of 4 sounds, children aged 8-9 years, although the study only addressed the major mode [34]. Most of these melodic contours have been incorporated into the programming of CANTUS, showing the use of tonal supports *d m s*, and passing notes between tonal supports, and repeated notes as fundamental characteristics especially in the first units.

## 1.5 Educational technology applied to intonation and music reading

The technology applied to the singing voice has been developed by study and graphical display of waveforms emitted, in real time in projects like *VOXed* [22] [23] [46] [48]. In a review study on major support tools based on real-time feedback for the training of singers [21] they analysed utility systems such as *Singad, Albert, Sing & See* and *WinSINGAD*. The application of these systems has resulted in both quantitative and qualitative studies that confirm the effectiveness of real-time visual feedback in improving the skills of singing. This is the reason for their inclusion in CANTUS, whose main objective is music reading and intonation.

Previously, Welch [43] emphasized the advantages of real-time feedback in his famous theoretical model reproduced here (Fig. 1). We can observe a) the modelling process by sequential imitation, and b) the modelling process with feedback on real time. The representation of KR during voice response also offers the possibility to modify the response immediately while observing its effect.

The *SINGAD* system was experimentally tested with 32 children aged 7 [46]. Later, in the *Albert* and *Sing & See* systems, controllable vocal parameters were expanded as singing training, pronunciation training, speech therapy and speech or timbre identification (spectrogram).

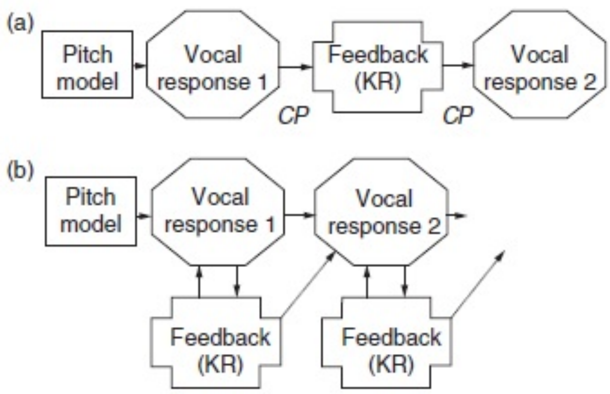


*Fig. 1: Welch Model*
*(CP = Critical learning Period KR = Knowledge of Results) [43] adapted [41].*

A multidisciplinary group of singing teachers, singers, psychologists and scientists voices, using an action research methodology, developed the *WINSINGAD* system. It allows to study parameters such as input waveform; sound fundamental frequency ($F_0$) in relation to a timeline; short-term spectrum; narrowband spectrogram; Spectral relation in relation to time; vocal tract area (VT, the distance between the glottis and the lips); and average / min VT area versus time. Any parameter can be displayed on the screen in combination with another.

In relation to the visual representation of the vocal response it has been suggested that there may be a feedback which helps singers in training to improve their pitch accuracy [48]. Although the immediate effects of a concurrent visual feedback lead to decreased performance, due to cognitive overload of the process, eventually it enhances singers performance.

Programmes on music reading with computers has been limited in many cases to auditory aspects, interval recognition, musical dictations or placement of notes by name on the staff. In other cases students have been assessed by the introduction of the note read through a keyboard.

Other software for computers such as Singing Coach or for mobile phones as Sing Sharp or Learn to Sing require to record their voice, and include the graphical representation of it, but do not include a systematic assessment process that can be useful to teachers for analysis or evaluation.

# 2 DIDACTIC DESIGN

The main goal of CANTUS is to read Western music notation with the voice (intonation). The principles included in CANTUS are:

- Training by vocal imitation using both Solfeggio syllables and the neutral syllable. The neutral syllable enables the learner to practice relative Solfeggio, used in most of the twenty century's music methods.
- Presentation of tonal patterns without the rhythm component. Each pattern has 2-8 sounds. The patterns are distributed in 5 work units, which are designed to practice reading and intonation of notes on the treble clef. The patterns use major mode (with and without flourish notes), Doric and Eolic modes (with and without major seventh), Myxolidian mode, and the use of passing notes. Furthermore, they include notes outside the modality (chromatics, augmented and diminished intervals, etc.).
- Use of real time feedback for helping to the accurate intonation (see VOXed project).
- Visualisation of patterns in conventional treble staff and piano-roll.
- Assessment of the exercises included in each work unit –be by tonalities or by exercises-Also, it gives additional information about if the student uses the imitation or not –which is the same as saying the student is sight-singing.
- Adaptation to the student's pace by enabling the teacher to program and store patterns to use with students.

Due to these characteristics, CANTUS is a versatile training tool that can be adopted to all kinds of didactic systems for music reading and intonation. Also, it can be used for intonation with instruments.

The programming and organization of work units is based on methods that have foundations on tonal principles (Chevais, Martenot and Gordon). The learning sequence begins in the major mode with the upper fifth's flourish in order to approach the pentatonic scale (*so, la, so, mi, do*). The second work unit includes both passing and flourish notes –upper and lower-, so introducing Re and completing the pentatonic scale. Next and following a modal sequence as Orff [31] and Gordon [16], the minor modes are introduced to the students. Firstly, the Doric mode (work unit 3) (with and without raised seventh) and the Myxolidian mode (work unit 4). All exercises are contextualized with the tonic and fifth of the correspondent chord through a harmonic background because it is necessary to establish a clear reference with the tonic at all times, therefore within the tonality or modality. Work units include tritone (*diabolus in musica*), chromatics and other altered sounds out of the tonality or modality. These activities can be done in several tonalities.

# 3 SOFTWARE DESIGN AND IMPLEMENTATION

## 3.1 Software architecture

In sight of the growing variety of devices and operating systems used for software consuming, CANTUS has been developed in the basis of HTML5 technologies, providing cross-platform support. HTML5 is the fifth revision and newest version of the HTML standard. It offers new features that provide not only rich media support, but also enhance support for creating web applications that can interact with the user, his/her local data, and servers, more easily and effectively than was possible previously. Currently, the latest versions of all major browsers (Chrome, Firefox, Opera, IE) support HTML5 APIs that can be used with JavaScript. The following HTML5 APIs are particularly useful for the design and development of the software:

- The *canvas* element for immediate 2D drawing mode.
- Web Audio API, a high-level JavaScript API for processing and synthesizing audio in web applications.
- File API for handling file uploads and file manipulation.

CANTUS is therefore a web application. A web application or web app is any software that runs in a web browser. It is created in a browser-supported programming language (such as the combination of JavaScript, HTML and CSS) and relies on a web browser to render the application. Particularly, it has been developed as a full client-oriented application, meaning that the application is run entirely by the client browser and no operations are performed by external server machines. This significantly simplifies the portability and installation of the software. An architecture overview diagram is shown in Figure 3.

## 3.2 User interface

In contrast to complex audio computer programs, CANTUS has been designed to be a highly user-friendly and intuitive program for non-expert users by providing clear and simple interactions with users. Figure 2 shows CANTUS main interface, where the unit exercise list is shown on the left side, and the current exercise notes are shown on the music staff on the right side. Evaluation results are popped-up in a new window after every exercise attempt. Additionally, detailed user evaluation statistics are gathered during the session and can be consulted any time in a specific *evaluation results* page.


Fig. 2: CANTUS exercise user interface (listening to a note pattern).

The software also provides a custom exercise editor, where users/teachers can define its own set of exercises.

## 3.3 Evaluation algorithms

CANTUS automatically evaluates the pitch accuracy of the user's captured input for a given exercise. The evaluation is carried out in two steps: first, a Pitch Detection Algorithm (PDA) is used to estimate the pitch over the microphone-captured audio signal. Then, pitch mean values are calculated and compared with the reference frequency values of the corresponding exercise notes. Details regarding both steps are given in the following sections:

### *3.3.1 Pitch Detection Algorithm*

A PDA is an algorithm designed to estimate the pitch or fundamental frequency of a quasi-periodic or virtually periodic signal, usually a digital recording of speech or a musical note or tone. In CANTUS, it is used to calculate the pitch of what has been intoned (voice) or played (musical instrument) by the user in a given exercise. There are many different approaches and algorithms to perform this pitch estimation, most falling broadly into three different classes: time-domain, frequency-domain and spectral/temporal approaches. CANTUS implements the time-domain PDA algorithm known as *YIN algorithm* [8], which is based upon *autocorrelation*, a technique consisting of comparing segments of the signal with other segments offset by a trial period to find a match. YIN has proven to be a robust and accurate algorithm to perform real-time pitch tracking [40].

The pitch detection process starts with the audio capturing through the device microphone. Once the audio signal buffer is ready, the YIN algorithm estimates fundamental frequencies ($F_0$) through time, which will be later used to evaluate the intonation accuracy. Figure 4 shows an overview of the PDA process.

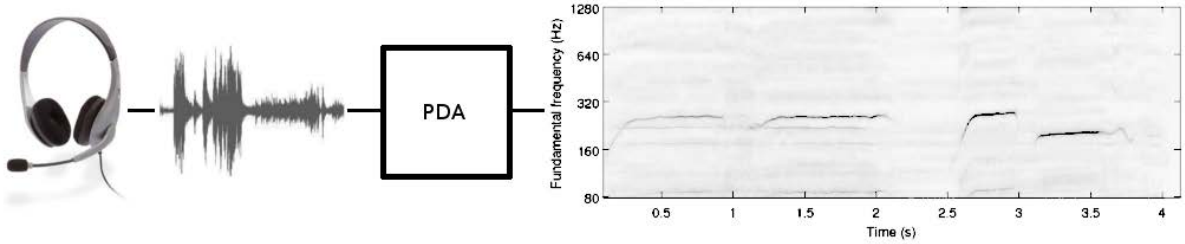


Fig. 4: Pitch detection process overview.

### *3.3.2 Intonation Evaluation Algorithm*

The Intonation Evaluation Algorithm will receive as input both the exercise reference note frequencies and the estimated frequencies ($F_0$) of the captured input signal, and will produce as output an accuracy score between 0 and 10 measuring the closeness of the latter to the former. The estimated frequency for each exercise note is computed as the median of the note's 60% central time-interval captured frequencies.

The algorithm evaluates notes separately, each of them counting for 10/*N* where *N* is the number of notes of the particular exercise. If the difference between the reference and the estimated frequencies is lower than a third of a semitone, then the note individual score is maximum (10/*N*). Otherwise, the note individual score is reduced proportionally to the semitone difference ((10/*N*)·(1-*sdiff*)). This semitone difference is calculated in an octave-independent manner. This means the notes can be reproduced in any octave without affecting the resulting score, which is particularly useful to reinforce the evaluation process among different audio sources (male voice, female voice, different musical instruments, etc.).

## 4 CONCLUSIONS AND PROSPECTIVE EVALUATION

This software aims to facilitate the teacher's task in the processes of teaching intonation. In this sense, CANTUS is a tool that students can use inside and outside the classroom as an intonation exercises generator. It helps to develop some automatic skills both in the area of reading Tonal Western notation as well as developing the motor skills required to emit the voice in tune. This software fills an important gap in the area of musical training using computers. First, because it can be used as a training tool. Second, because with this tool the teacher can develop their own exercises, thus, customize them according to the individual needs of each student. However, what has been presented in this paper is an ongoing investigation. Obviously, the next phase in this research was the quantitative and qualitative evaluation, not presented in this paper due to the limited space. This evaluation was conducted using two instruments: a questionnaire and focus group interviews. We collected data from students and music teachers after using the software. CANTUS is intended to be not only a tool for music reading and intonation for the voice, but also for musical instruments. This will be a new project once the product of this research is evaluated and disseminated.

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