A Digital Bagpipe Chanter System to Assist in One-to-One Piping Tuition

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ABSTRACT

This paper describes an electronic bagpipe chanter interface and software system, developed to assist in one-to-one Highland piping tuition. The chanter employs infrared reflectance sensors to detect the continuous movements of the player's fingers, and incorporates an air pressure sensor in place of the chanter reed, allowing it to be connected to a traditional acoustic set of pipes. The software is intended to assist the instructor in communicating feedback to the student by providing facilities for recording, playback, visualisation and comparison of teacher and pupil performances. A user study of the system was carried out with an experienced piping instructor and seven students. The sessions yielded encouraging and constructive feedback from both students and instructor, and produced promising avenues for further work.

1. INTRODUCTION

The Great Highland Bagpipe (GHB) is widely regarded, at least among pipers, as an instrument with a high barrier to entry. The Highland piping tradition requires the aspiring player to memorise a diverse array of distinct and formally defined ornamentation techniques before attempting all but the simplest of tunes; a process that can often take six to twelve months of regular and disciplined practice. Historically, bagpipe music was passed on through the instructor singing to the student in a precise musical language known as *canntaireachd*. Indeed, piping notation is a comparatively recent development, having been introduced in the early 19th century [1]. The use of sheet music in bagpipe lessons is now reasonably common. Nonetheless, GHB music is generally devoid of any phrase markings or other high level performance instructions of the kind that might be seen in classical music notation.

The GHB provides no facility for dynamic control, and produces a constant, uninterrupted sound, preventing the use of silences or timbral changes for the purposes of emphasis or articulation. Variations in rhythmic phrasing are thus an integral aspect of expressive bagpipe performance, and one of the primary means by which proficient pipers can convey their own interpretations of the otherwise largely inflexible traditional repertoire.

Communicating such subtle temporal deviations can be a challenging task for piping tutors. While singing or playing a passage for the student to repeat is undoubtedly effective, it is often necessary for the teacher to verbally describe their intentions. This can lead to the use of somewhat abstract language such as "push out the first beat" and "the G gracenote takes you to the E doubling on the beat", which can be difficult to understand, even for students with significant experience of other musical instruments.

The aim of this work is to develop teaching tools which are specifically tailored to the requirements of the piping community, with the goal of assisting and accelerating the learning process in the context of one-to-one lessons. This paper presents a digital GHB chanter interface and accompanying software system which enables the recording, playback, visualisation and comparison of teacher and pupil performances. This is intended to help the instructor illustrate and convey feedback to the student.

2. RELATED WORK

2.1 Electronic Bagpipes

Several brands of electronic Highland bagpipes are commercially available, of which the DegerPipes [1], TechnoPipes [2] and Redpipes [3] are most prominent. These use single capacitive touch-switches in place of the finger-holes, which are binary in nature; the "holes" are always either fully open or closed. This does not accurately reflect the finger-holes of an acoustic chanter, which can be gradually covered and uncovered to slide between notes.

There have been several attempts within the academic community to develop alternatives to this discrete sensor strategy. The FrankenPipe [2] uses photoresistors mounted inside the holes of an acoustic GHB chanter. This provides a wide analogue range for each hole, and has the advantage of retaining the physical feel of a traditional chanter. The EpipE [3] is a uilleann bagpipe chanter interface, which extends the capacitive sensing approach to include an array of sixteen small binary touch-switches for each hole.

While the Redpipes and EpipE have the capability to measure the pressure exerted on the bag by the player's arm (e.g. using force-sensitive resistors), the authors are not

[1] http://www.deger.com/
[2] http://www.fagerstrom.com/technopipes/
[3] http://redpipes.eu/

aware of any existing electronic chanter which can be connected to a standard set of bagpipes and controlled directly using air pressure. The interface presented in this work achieves this using an air pressure sensor similar to those employed in experimental wind controllers such as the CyberWhistle [4] and *The Pipe* [5].

2.2 Technology in the Context of Music Tuition

The use and development of technological tools for musical education is an active field of research. A significant proportion of existing work in this area is concerned with piano pedagogy using MIDI input from a digital keyboard, due at least in part to the MIDI protocol providing a simple means of capturing multiple aspects of a performance. One such project is the Piano Tutor [6], which combines score-following software and performance evaluation algorithms with extensive multimedia feedback in order to "create a natural dialogue with the student". The *pianoFORTE* system [7] produces visualisations of tempo, articulation and dynamics of a performance in the form of an annotated musical score. In addressing the development of tools to assist in one-to-one instrumental instruction, the authors assert that the aim is not to automate the teacher, but to facilitate the "difficult communication process" through which the instructor attempts to describe the subtleties of expressive interpretation beyond simply playing the correct notes.

The *MIDIator* [8] program takes MIDI input to allow the user to compare separate renditions of the same piece by producing graphs to illustrate variations in tempo, note velocity and duration. In addition to MIDI, the SYSSOMO system [9] uses raw audio, video and motion data from accelerometer and gyroscope sensors to capture a comprehensive record of a pianist's movements. A score following algorithm is employed to align and superimpose two performances with different tempi, enabling direct visual comparison between the playing of instructor and student.

The *i-Maestro* tool [10] records audio, video and VICON motion capture data of musicians playing bowed string instruments. This information can be played back and displayed in a variety of formats to help the tutor "identify, illustrate and explain certain issues involved with performance". The Digital Violin Tutor [11], intended primarily as a solo practice tool to provide feedback in the absence of an instructor, employs a transcription algorithm to visualise and compare the student's playing with an existing score, or earlier recording made by the teacher.

A study by the Office for Standards in Education (Ofsted) in which inspectors visited 52 schools around the UK highlights several ways in which technology can "enable attainment", "enhance progress" and "increase pupils' motivation" in music classroom contexts [12]. It is again noted that the tools should not take over the role of teacher, but should instead be employed to help clarify conceptual information for the student. For example, in lessons concerning critical listening, tutors could reduce or enhance the level of certain parts of a multitrack audio piece in order to help pupils focus on musical features which were previously imperceptible.

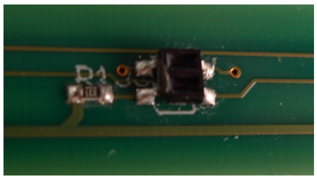


Figure 1. Close-up of infrared reflectance sensor.

Figure 2. Complete chanter and PCB.

3. HARDWARE DEVELOPMENTS

3.1 Physical Construction and Sensing Strategy

The purpose of the electronic chanter hardware is to detect the continuous movements of the player's fingers quickly and accurately, and to transmit this data to the host computer via USB. The interface described in this paper extends a prototype first presented in [13], which employs infrared (IR) LED and photodiode pairs for each hole, between which a constant IR beam exists. The player covers the "hole" by interrupting this beam with a finger.

This strategy was successful in providing a continuous analogue reading for each hole. However, the physical construction of the original chanter led to a somewhat unnatural playing experience, primarily as a result of being built using strip-board and through-hole components. The spacing between the sensors was dictated by practical layout constraints, and the requirement that the player's fingers sit between the IR emitter and detector prevented the board from being housed in a cylindrical shell. While appropriate as a tool to investigate the ornament recognition concepts that were the focus of the previous work, this interface was deemed unsuitable for use in studying the existing playing technique of piping students in a lesson.

One of the primary concerns when developing the improved hardware was therefore to make the physical playing experience as similar as possible to a traditional GHB. A custom printed circuit board (PCB) was designed, employing an integrated IR reflectance sensor for each hole (Figure 1). The distances between the sensors reflect the hole spacing of an acoustic chanter.

Each sensor is comprised of an IR LED and phototransistor in a single package, both directed upwards. When an object comes within range of the sensor, the IR radiation from the LED is reflected back and detected by the phototransistor. This allows the proximity of the player's finger to the sensor to be measured with a high degree of precision. Moreover, this sensing strategy allows the board to be mounted inside a cylindrical casing with real holes, providing a more realistic playing experience than contact dependent approaches such as capacitive touch pads. The completed chanter and PCB are shown in Figure 2.

3.2 Microcontroller Processing

The PCB incorporates an ARM 32-bit Cortex-M3 microcontroller which gathers and processes the raw sensor data before transmitting it to the computer. Timing synchronisation is handled by the onboard clock. The board sends one complete 20 byte message via USB every millisecond, providing accurate temporal information about the performance. Each message is comprised of a timestamp and nine sensor values in a packed binary representation.

For the interface to be effective in accurately measuring the player's finger movements, it is important that the sensor readings are as stable and reliable as possible. Each of the IR sensors is therefore read eight times during every millisecond period and an average taken to reduce the effect of inaccuracies caused by momentary fluctuations. Moreover, since the sensing strategy uses optical reflectance, it is necessary to account for variations in ambient light. By measuring the output of each sensor with the LED off directly after each reading, an indication of the current background conditions is obtained. This measurement is subtracted from the original sensor reading, ensuring that the final value is robust to environmental interference.

3.3 Air Pressure Sensor

In addition to the intricate fingering technique needed to reproduce a melody on the chanter, the GHB requires a steady flow of air through the chanter and drone reeds. This involves applying a constant pressure to the bag with the arm, and a significant degree of physical exertion to keep the bag filled with air. These essential aspects of bagpipe playing cannot be addressed using a standard practice chanter (a quieter single pipe instrument with no bag, sounding roughly an octave below the GHB), and thus regular practice sessions on a full set of pipes are traditionally required to maintain the necessary endurance. However, the high sound intensity levels involved can render this impractical for many pipers (e.g. those living in urban areas).

Therefore, a technological system that allows the user to work on the breathing and arm pressure elements of GHB technique at any volume (or wearing headphones) could provide significant benefit to the piping community. To achieve this, the hardware developed in this work incorporates a MPXV5010 pressure sensor at the top of the PCB, and a small hole for the air to escape as it would through a conventional chanter reed. By closing off the drones of a standard set of pipes using stoppers and inserting the electronic interface into the bag in place of an acoustic chanter, the player can control the instrument using exactly the same physical interactions as with a traditional GHB.

This provides a complete and realistic playing experience, and allows the user to practice all aspects of Highland piping technique without any acoustic sound being produced. Moreover, the pressure at which the drones and chanter sounds are activated can be specified and modified in the software, enabling the player to adjust the strength of the virtual "reeds" and progressively develop stamina.

4. TUITION SOFTWARE SYSTEM

4.1 Communication and Audio Output Software

The aim of the work presented in [13] was to produce an algorithm for automatic recognition of Highland piping ornamentation. This was intended primarily as a solo practice tool to provide novice pipers with immediate feedback on their technique in the absence of an experienced tutor, in order to avoid the introduction of bad habits between lessons. By contrast, the focus of this paper is not on style-specific machine intelligence, but rather the development of an analytical tool to assist piping instructors in communicating their feedback to the student during a lesson.

The software framework consists of three components which communicate via the Open Sound Control (OSC) protocol [14]. A simple command line utility receives and interprets the incoming serial data from the chanter. The unpacked sensor readings are transmitted to two separate programs: the tuition software; and a standalone SuperCollider [15] application that produces the audio output. Rather than employing a wavetable synthesis approach as in commercially available digital chanters, this system instead uses sampled GHB recordings. Given the stationary nature of bagpipe sounds, and the lack of expressive parameters in interacting with the traditional instrument, this method provides a highly convincing sound. Moreover, the system can be easily extended to include samples from other varieties of bagpipe such as the Scottish smallpipes.

4.2 Functionality of Tuition Software

Experienced Highland pipers frequently employ creative rhythmic phrasing around the strong beats of the bar to add expression to their playing. While an important aspect of advanced performance, which many proficient players may understand intuitively, these subtle temporal variations can be difficult to describe. The purpose of this program is therefore to provide an illustrative tool to aid the tutor in describing and explaining their comments on a student's technique. This requires the ability to capture the performance and to represent it in a clear and intuitive format.

The system allows the instructor to record a piece of any length, tempo and time signature to a metronome track. This performance can then be displayed on screen as shown in Figure 3. The visualisation uses the traditional staff system to illustrate pitch (maintaining the piping convention of omitting the accidental symbols on the C♯ and F♯) and barlines are shown. Note duration is portrayed using a proportional notation similar to the familiar piano roll format. This representation allows the nuances of a player's rhythmic phrasing, which would be obscured by standard classical notation, to be clearly and explicitly depicted.

Using the instructor's recording as a guide, the student can attempt to play the same piece. While recording, a playhead scrolls through the staves to illustrate the current point in the sequence (continuing onto multiple pages if necessary), and the results of the pupil's playing can be shown contemporaneously or hidden as preferred. Once complete, the two performances can be displayed either individually or overlaid in different colours (Figure 4), al-

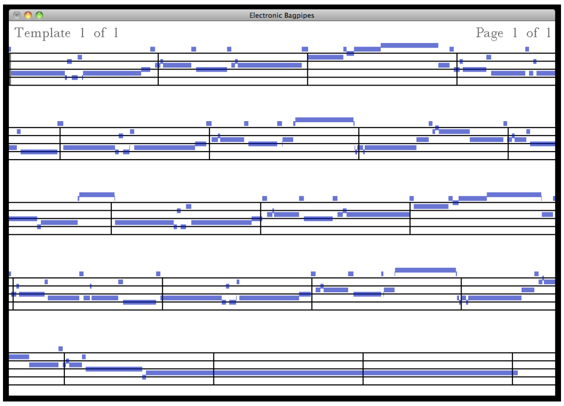


Figure 3. Visualisation of instructor's performance.

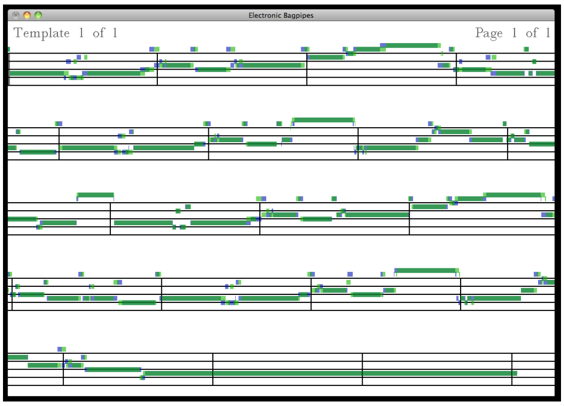


Figure 4. Instructor and student performances overlaid.

lowing subtle variations in timing to be identified and examined visually. Since aural training is a crucial aspect of musical learning [16], the recordings can also be played back from any point, separately or together, and at varying playback speeds by clicking on the screen. This enables direct and repeatable comparison between the two, promoting critical listening on the part of the student and providing the instructor with an additional tool with which to explain their feedback. The system also includes the facility to log performances, such that they can be reopened in future sessions to gauge ongoing progress.

4.3 Illustrative Example of Tuition Software

Figure 5(a) shows the Highland piping notation for high A to low A with a *birl* ornament on the first beat of the bar. It is standard practice in GHB music that the stems of all melody notes point down, while embellishments are written as demisemiquavers with smaller note heads and stems pointing upwards. It is important to note that ornaments are not assigned any durational value in the score; a bar of $\frac{4}{4}$ will contain four full crotchet melody notes regardless of the number of embellishments. This can cause significant confusion as to how and where an ornament should be played, particularly among piping students who already have some experience with other musical instruments.

While there are some general guidelines as to where certain embellishments should be performed with regard to the beat, this is one of comparatively few aspects of Highland piping which is open to interpretation by the player. Instructors will therefore seek to guide their students towards particular phrasing characteristics depending on the desired expressive effect.

Figure 5 illustrates how the visualisation software can be used by the tutor to help explain the nuances of such feedback. A straightforward interpretation of the notation from Figure 5(a) would involve the birl ornament being played directly on the beat, as shown in Figure 5(b). A more experienced player may instead wish to perform the embellishment fractionally earlier, in order to give the piece a more "lively" edge. This is clearly visible in Figure 5(c).

Such concepts are not easily described, and piping ornamentation is executed so quickly that even practical demonstration by the instructor is not always sufficient to fully clarify the distinction between the two renditions. The software system presented in this work provides a simple and unambiguous visual representation of subtle temporal variations in order to assist the tutor in conveying this central aspect of Highland piping technique to students.

5. USER STUDY

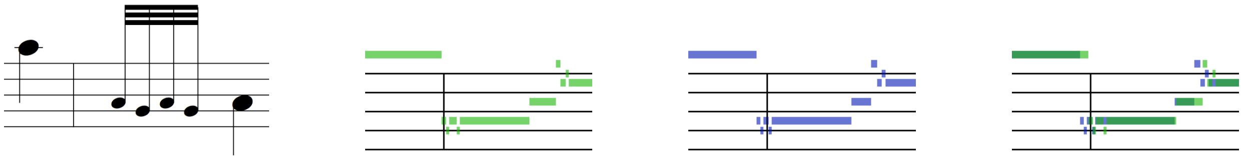
5.1 Location and Participants

An initial user study of the system was carried out at a private boarding school in the North East of Scotland. The study took place under the supervision of the school's piping instructor, a highly proficient piper with around thirty years experience of playing and twenty years of teaching, thirteen of which had been spent at the school. At present there are forty-seven piping students at the school, aged between eight and eighteen years. Based on his detailed knowledge of the pupils' playing, the instructor selected seven students to participate in the study. The participants were aged between thirteen and seventeen years, and their playing experience ranged from six months to eight years.

5.2 Purpose and Structure of Study

The study took place over a period of four days, the first of which was spent with the instructor only, in order to gather and address his initial comments on the system prior to using it with the pupils. A short interview was also carried out to learn more about his approach to teaching, and some of the particular challenges faced by piping instructors. In response to this discussion, some minor adjustments to the sensitivity of the finger position sensors were made in order to make the playing experience as similar as possible to an acoustic bagpipe chanter.

Each of the students had one session (between 30-60 minutes) with the digital chanter as part of their normal one-to-one lesson time. In each case the student was given some time to get used to the interface. The instructor would then record a tune while the pupil listened, following which the visualisation and playback mechanisms were demonstrated. The student was then instructed to play the same piece. Once the student had finished recording, the instructor would use the visualisation and playback functions to illustrate his observations about the pupil's performance. This process was typically repeated several times per lesson, often with different tunes.



(a) Standard notation for high A to *birl* on first beat.

(b) *Birl* ornament on the beat.

(c) *Birl* ornament leading into the beat.

(d) Both performances overlaid.

Figure 5. Example of how the visual display can be used to illustrate subtle variations in rhythmic phrasing.

5.3 Observations and Outcomes

5.3.1 Instructor Feedback

The developments made during this work with regard to how bagpipe teaching could be best supported using technology were largely informed by the author's personal experience as a piping student. During the introductory interview, the instructor indicated his agreement with many of these assumptions, saying of rhythmic variation in GHB performance that "pipe music is so different... the way we express our tunes isn't the way it's written". In particular, he described his experience of teaching the former Director of Music at the school, who had struggled with the phrasing of many ornaments, despite having a wealth of musical knowledge and proficiency with other instruments.

During the lessons, there were several instances in which the instructor identified specific ornaments which regularly caused the student to lose track of the beat as a result of incorrect phrasing. In such cases, it was possible to locate these points using the display and compare the two recordings both visually and aurally, allowing the pupil to analyse their own playing with the instructor's comments (e.g. "you're labouring the *throw on D* [ornament]") in mind. At the conclusion of the study, the instructor described the system as "a great idea" and "such an interesting piece of kit", saying that he could definitely envisage it being used regularly in his lessons. Furthermore, he felt that the proportional notation provided an intuitive means of visualising rhythmic phrasing, and stated that even he had found it helpful in illustrating exactly how he played certain embellishments relative to the beat.

In addition to its use in lessons, the instructor suggested that the system could also prove to be a useful tool for solo practice. During lessons, he regularly asks his pupils to identify for themselves how their performance could be improved before providing feedback, so as to promote critical listening to their own playing when practicing alone. By using the system to identify problem areas and repeatedly comparing their recorded performance to the instructor's template, the student could keep track of their progress and avoid introducing bad habits between lessons. Moreover, the instructor indicated that one of the major challenges in teaching the bagpipes is to maintain the students' levels of enthusiasm. To this end, he described the system as "a fantastic thing to get people enthused".

The instructor also offered a number of suggestions for how the system might be improved. Some of these concerned minor refinements to enhance the physical playing experience, and were amended during the study. Criticisms pertaining more generally to the high-level affordances of the system will be addressed in future work. The instructor felt that by providing the facility for tutor and student to record simultaneously using separate electronic chanters, a more meaningful illustration of the differences in rhythmic phrasing might be obtained. He also suggested that the software could be used to indicate instances of *false fingering*, which refers to the practice of playing a note with the top hand (e.g. high A), without correctly executing the corresponding bottom hand fingering. While considered extremely bad practice in traditional Highland piping, this can be a difficult habit to diagnose and correct, particularly when playing quickly, as the resulting note is generally very close to the desired pitch.

Likert statement	Mean response
I found the physical feel of the digital chanter was realistic to play.	4.2 / 5
I found the sound quality realistic.	4.0 / 5
I found the system easy to use.	4.4 / 5
I found the display easy to understand.	4.2 / 5
I found the system fun to use.	4.8 / 5
I think the system would be useful as a practice tool.	4.6 / 5
I would use the digital chanter system in my lessons and practice.	4.4 / 5

Table 1. Average student responses to survey questions.

5.3.2 Student Feedback

Following the sessions, students were given a short survey consisting of seven Likert-type questions and a box for additional comments, which was completed by five of the seven participants. Possible answers ranged from 1 ("strongly disagree") to 5 ("strongly agree"). Table 1 shows the mean response for each question. The numerical results indicate that the system was well received by the pupils. The lowest score was 4.0 for the perceived authenticity of the GHB sound, which may well be improved if the audio were to be reproduced through headphones or a loudspeaker system of reasonable quality rather than the built-in speakers on a laptop. The result of 4.6 in response to the statement "I think the system would be useful as a practice tool" is particularly encouraging, and the 4.8 reaction to "I found the system fun to use" is aligned with the instructor's assertion that it could help generate and maintain enthusiasm for practicing. The students also suggested several possible improvements to the system, which included a zoom feature to focus on specific sections, and making the operation of the software more intuitive for the user.

5.3.3 "Bagpipe Hero"

One significant addition to the system during the course of the study was the inclusion of a more game-like interface for the student to record along to the instructor's performance, loosely inspired by the popular "Guitar Hero" series. This development was prompted by the instructor's suggestion that providing a score for accuracy might help the students gauge their progress. In *Bagpipe Hero* configuration, the template notes approach a fixed marker on the staff which indicates the current note on the digital chanter.

The reaction from the students was decidedly positive; all stated that they would be more inclined to practice in their own time if the Bagpipe Hero system was set up in the school. In particular, when the instructor suggested that if a Bagpipe Hero leader board was set up each time a new tune was introduced to the pipe band, one pupil agreed that the motivation to practice would increase because "you'd want to beat everyone." Other feedback included "This thing is cool", and "it's a lot of fun; I want one!".

An interesting observation made by the instructor regarding the Bagpipe Hero system was that several pupils seemed to emulate the template performance significantly more accurately than with the original visualisation (playhead moving through stationary notation). One participant felt that it "helped quite a lot because you know how long to hold each note on". Another student, a relative beginner who had been playing for around six months, struggled greatly when recording to the metronome, and rarely held the beat for more than a few bars before rushing into the next phrase. Subsequent investigation of the original recording indicated less than 11% accuracy. On the first attempt with Bagpipe Hero mode, the student achieved 65% for the same piece, which the instructor described as "an unbelievable difference".

5.4 Conclusions

Feedback from this preliminary user study of the digital chanter system has been both positive and constructive. The instructor felt it had significant potential to be a valuable teaching tool in one-to-one piping lessons, and could also prove useful for solo practice. The study also yielded some promising avenues for further work (e.g. the capacity to highlight false fingering) and some important criticisms regarding the user interface design which will be addressed in the near future. The inclusion of some variant of the ornament recognition algorithm presented in [13] might also prove interesting, particularly for individual practice.

Acknowledgments

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