THE SOUND OF ONE ARM SWINGING: A MODEL FOR MULTIDIMENSIONAL AUDITORY DISPLAY OF PHYSICAL MOTION

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ABSTRACT

We present a novel approach to the sonification of complex human movement. As a specific model we examine the golf swing, of which two components, the velocity of the club head and the relative rotation of shoulders with respect to the hips (the X-factor [1]) are considered as two critical factors [2]. We map these dimensions to independent resonant filters to simulate vowel like formants. We consider other methods of sonification and illustrate the advantages of using vowel sounds. This sonification creates an auditory mapping that may prove useful in mastering and improving a golfer's swing and can be generalized for sonification of complex temporal data.

1. INTRODUCTION

Golf has one of the highest learning curves of all recreational sports, yet it has neither complicated rules, nor requires a strong physique. It is a game of finesse. The golf swing is known to be unnatural, notoriously difficult for beginners to learn and even tougher to master. Inspired by the role of auditory feedback in learning to bow a stringed instrument, we explore the potential of sonification of the golf swing as a means to understanding and mastering this complex movement.

We first consider a derivative of a simple pitch based mapping developed by Grober [1][3]. We next propose an improvement to this model based on the bifurcations of the difference equation. We assess these approaches from a perceptual standpoint. Finally, we describe the use of formant based vowel synthesis to achieve more effective auditory feedback of the swing.

2. THE GOLF SWING

The golf swing begins with a backswing to the point where the golfer's torso is fully rotated. The golfer then begins the swing by rotating his or her body increasing the velocity of the club head through this rotation force. An ideal golf swing maximizes velocity and control of the club head at the time of impact with the ball. The rotational velocity should peak at the point of club impact. Golfers refer to this rotational component as the "X-factor", which describes the rotation of the shoulders relative to the waist. After impact, the golfer lets the momentum follow through naturally. In addition to velocity and x-factor, the tempo of the swing is crucial. Consistent tempo will allow for the maximum velocity while still maintaining control over the ball. Many golfers will listen to metronomes or music at a certain BPM to regulate their tempo.

These three factors, club head velocity, and X-factor and swing tempo will be used in these sonifications of the golf swing.

3. MAPPINGS

3.1. Pitch and Pan

An example of direct parameter mapping is to use frequency to represent velocity and spatial location for the right to left rotation of the shoulders (X-factor). For location we used simple stereo pan. The major problem with this method is that it requires the golfer to have refined pitch perception since even small changes in the velocity of the swing can lead to a poor result. Unfortunately those differences are difficult to differentiate due to the speed of the swing and the shortcomings of most people's pitch perception skills. This perceptual shortcoming also prevents post swing analysis, since it is hard to compare two different pitches.

However, mapping the X-factor to the stereo panning is both intuitive for beginners and is a crucial factor for determining when the ball is hit. The sound should be in a 50/50 balance between left and right at the time the ball is hit. This way the golfer can hear if they are hitting the ball too soon or too late. In our sonifications we used an exponential system of balance to so that the sound should appear to fade linearly as the shoulders rotate at an exponential rate. Despite the simplicity of this direct mapping, the issues of pitch acuity and spatial perception render this sonification approach limited in value.

3.2. Bifurcations and a Stabilized Path

The second method of sonification we developed relies on a previously built database of ideal golf swings from professional golfers, as well as swings calibrated to each individual. The sonification will be silent during a correct swing, but when the club head leaves the "correct" plane it will provide feedback at a volume and intensity proportional to its distance from the plane. Here we will use the logistic difference equation:

$$x_{n+1} = rx_n(1 - x_n) \tag{1}$$

The further the club head is from the plane the larger the r coefficient will be. When r is between 2.8 and 3.4 the equation will bifurcate further and further apart. Past 3.4 the equation will continue to split until it eventually produces chaotic values between 0 and 1. When it is on the correct plane the sound will be a constant note, but as it moves further from the plane the

equation and the sound will begin to bifurcate and eventually become completely chaotic. The speed that these bifurcations are played back could be related to the intrinsic tempo of each golfer.

While the difference equation improves on a simple pitch mapping it is not without its own shortcomings. Unfortunately the swing happens so quickly that the bifurcations seem to lag behind the position of the club in the shot. Thus, the feedback is delayed so it is impossible for the golfer to make real time adjustments in their swing. While a model based on bifurcations may be appropriate for slower movements, the speed and variability of a golf swing make it an impractical model.

4. VOWEL MAPPING

4.1. Formant Synthesis

The third method uses vowel synthesis as a basis for intuitive auditory display as proposed in [4]. We chose to depart from current work in a physical model of the vocal tract and instead work with formant filter based synthesis. This method allows for audible transitions between vowels. For example a sound can be produced with some oh and some ah character. This allows one to hear the vowels morph into each other. Second it does not require large amounts of processing power so that the swing data can be sonified in real time.

Formant synthesis works by running a pulse train through a series of resonant filters (at least two) to mimic vowel sounds. The first two filters have the strongest effects on the sound and thus they will be controlled by our parameters.
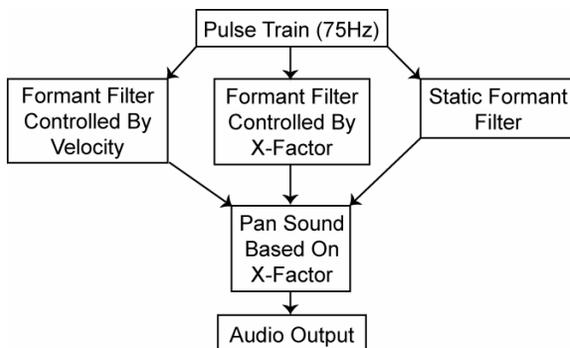

Figure 1. The golf swing sonification engine created with three formant filters. The third formant filter is not controlled by any variables and remains static throughout the sonification.

4.2. Formant Filter Mapping

Using a Cartesian plane, we mapped the frequency of filter one (velocity) to the y-axis and the frequency of filter two (X-factor) to the x-axis. We then anchored the sonification around three vowels: ah, eh, and oo. A normal backswing starts with eh and then moves towards oo as the backswing velocity peaks. Then as it begins to rest in the full backwards position, the mapping moves back towards eh. As the downswing starts, the sound quickly moves to ah where contact should be made and then follows through to rest on eh.

The three sounds ah, eh and oo were picked due to their distinct sound yet relative proximity to the vowel oh. The vowel oh while not directly involved in the sonification can be used as a way to describe the swing. For example a swing that is too slow on the downswing will have a greater amount of oh character than ah character.

Because of human sensitivity to phonemes it is relatively easy to adapt this system into a compact and easily learned means of auditory feedback. For example a coach might tell his student 'reach for the pure 'ah' sound' or 'try to eliminate the 'oh' from your swing'.
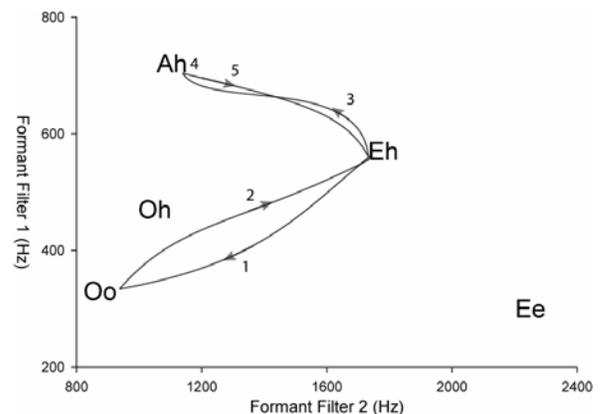

Figure 2. An example swing superimposed on a derivative of the Peterson vowel chart [5][6]. The arrows show the direction of the swing across the vowel map. While most swings will usually hit the target vowels, the paths may differ drastically from golfer to golfer.(1) The beginning of the backswing (2) The end of the backswing (3) The beginning of the downswing (4) Contact with the ball (5) The follow through

5. DISCUSSION AND CONCLUSION

Although we have not yet widely tested the efficacy of the system, we believe that phoneme based sonification of the golf swing achieves our two goals. It can be used to teach beginners how to properly play golf using real time auditory feedback and can be used to analyze golf swings by understanding the different vowel characters of the swing. The most obvious shortcoming of phoneme based sonification is cultural and geographical variability in perception. However the system is easily adaptable by recalibrating the vowel mappings.

6. FUTURE WORK

We are currently exploring the use of granular synthesis in which grain size corresponds with swing speed such that the smaller the grain size the faster the swing velocity. This method of the sonification could be effectively combined with phoneme based sonification.

Future work will involve creating an experiment design that will allow for validation of our premise that auditory feedback, and in particular phoneme based sonification, is effective in improving performance.

Finally, while this paper focuses on sonifications of the golf swing, the methods described in this paper could be more generally applied to any multidimensional system where auditory feedback could aid in skill based acquisition.

Auditory feedback is a necessary component for musical skill acquisition. For example, imagine learning how to sing without being able to hear your own voice or learning how to bow a cello without hearing the sounds the instrument makes. One cannot explain in instructions how to bow a cello, the musician must experiment and using auditory feedback make adjustments until the desired sound is made. We believe that the same mechanism is in effect in the golf swing. By adding auditory feedback to the golf swing, the golfer will be able to receive real time information about his or her swing. Instead of knowing a good swing by where the ball lands, the quality of the shot can be known during the swing and the golfer can hear where he made a mistake. Pro golfers will often talk about "feeling" the swing or aiming for the "sweet spot". Using this sonification the golfer can "feel" the club with his ears and hear the sonified "sweet spot".

6.   ACKNOWLEDGEMENT

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