Acoustic metrology: from atmospheric plasma to solo percussive Irish dance

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Abstract: LabVIEW software is used to decode step sequences generated by Irish light and hard shoes and bare feet. To remove the low frequency reverberation of the floor a Savitzky-Golay digital filter is used to de-convolute the percussion sound of the step sequences. Floor types and foot apparel are compared.

1. Introduction

In the last 5 years acoustic metrology [1, 2, 3 and 4] as a means of controlling an atmospheric pressure plasma-surface manufacturing processes has been developed. The origins of this metrology go back to W. Duddell's [5] and V. Paulson's [6] ionised gas sound production experiments at the turn of 19th - 20th century when radio technology was in its infancy. Today's atmospheric plasma metrology uses advanced digital time- and frequency-domain instrumentation linked to principal component analysis techniques to capture the interaction between the plasma and treated surface. This work extends this acoustic metrology into the world of solo step dance, in particular the examination and comparison of Irish hard shoe, Irish light shoe and bare feet. The percussion plates on Irish hard shoes are constructed from fibreglass or fibreglass composites. These are constructed in a solid piece and are fixed to the base of the front of the shoe with glue and to the heels with nails/screws. American tap shoes use plates constructed from a thin piece of steel and are loosely fixed to the shoe using screws. This difference in material and shoe/plate bonding results in a very different sound signature between the two shoe types. The Irish shoe gives a deep 'woody' sound when struck, while the loosely fixed steel plates of the American tap shoe has a hollow 'tinny' sound. The loose bonding of the American percussive plates result in a distinctive double tap per strike while the tightly adhered Irish plates result in a single tap per strike. These two distinctive toe and heel tap styles are universally used in record attempts in speed dancing. We use sound recording software that was developed to capture and analyse

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atmospheric pressure plasma acoustics. To evaluate the techniques we sample and compare bare feet and Irish light shoes, and Irish hard shoes striking a ceramic tiled floor and a wooden surface.

2. LabVIEW software

The sound recording and deconvolution analysis used in this study uses National instrument LabVIEW 20011 software program running on a Dell laptop. The recordings where made using a standard sampling rate of 44100 S/s and a 24 Bit depth. Decoding of recorded time-series dance rhythms and an Irish traditional dance sequence, danced to the tune of 'Abe's axe', a reel from Gráda's Natural Angle album (Compass Records), are used to demonstrate how a Savitzky-Golay (SG) moving window digital filter [3, 6] can be used to piece-by-piece de-convolve the low frequency reverberation response of the floor surface (wood and tile) as the dancers shoes (and bare feet) strike the floor surface. The SG filter uses a least square minimisation operation with a polynomial function ($m = 1$). The windowing operation is expressed in the following form, where k is the $\pm$ sampled data points. The block diagram of the LabVIEW deconvolution software is shown in Fig 1.
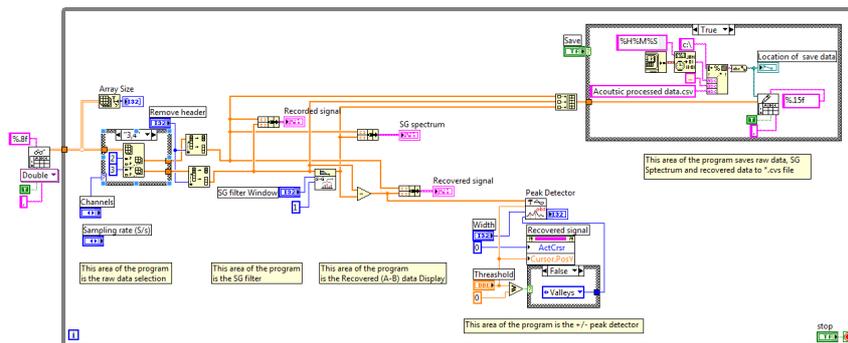
$$2k + 1 \hspace{4cm} (1)$$

Figure 1: Block diagram of LabVIEW de-convolution software

2.1 Dance shoes

The Irish dance shoes used in this study are manufactured by Hullachan Pro. (Glasgow, Scotland). The Irish light shoes are the Hullachan H1 leather soled pumps while the Irish hard shoes are Hullachan HIJ Jig shoes with fibreglass composite percussion plates on the toes and polyurethane top on the heels.

3. Results

Three sets of dance recordings were made and the recordings analysed using the NI software program. The first and second set of recordings where taken of two subjects (one female and one male, having a European shoe size of 38 and 41,

respectively) dancing to the rhythm of 'Abe's Axe'. In the first test the dancers were in bare feet and then the female dancer with Irish light shoes. Finally both wore the traditional Irish hard shoe. The floor surface was also changed from wood to ceramic tile. The sound recordings were taken at distance of 1 meter for the bare feet sequence and 3 meter for the shoe recordings. The third set of sound recordings where taken with the dancers wearing the Irish hard shoe and dancing to the rhythm of an Irish traditional step dance. Again a wooden floor and ceramic tiled floor were used. The results of the sound measurements and their de-convolution are set out in sections as follows: 3.1 surveys the four percussive impacts to the bar using bare feet and Irish light shoes; section 3.2 looks at the traditional Irish step dance. And section 4 provides the conclusion.

3.1. Bare feet and Irish light shoes

In this section the LabVIEW software is employed to decode a sequence of 4 percussive impacts to the musical bar, which is repeated for 8 bars. The foot timing is kept by the dancer listening (through an ear piece) to the tune of 'Abe's Axe'. The recording microphone is placed 1 meter in front of the dancer. The 4 percussive impact sequence, which is repeated 8 times, is:

    1 = Right Toe
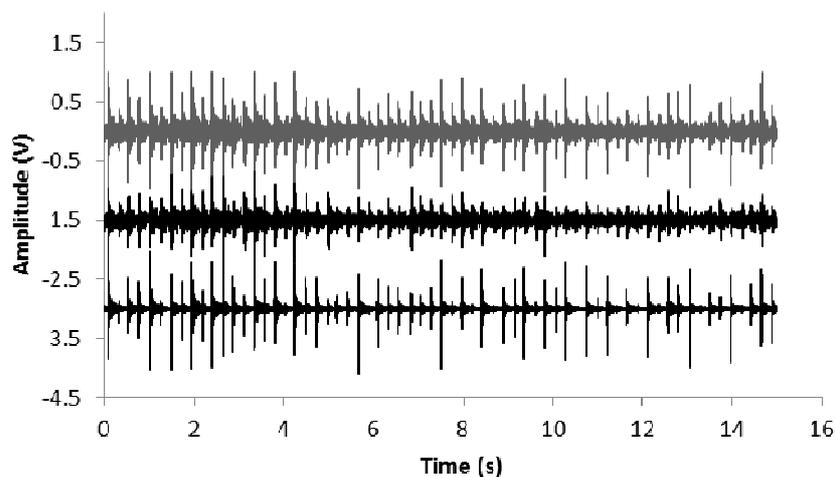   2 = Right Heel
    3 = Left Toe
    4 = Left Heel

Figure 2: Bare foot recording and its de-convolution. Upper trace is the raw recording, middle the sythenic floor and lower trace depicts the step sequence.

Figure 2 shows a triplet of time-base traces, for clarity each trace is offset from each other. The upper trace is the raw sound recording of a male dancer

performing the percussive sequence on a wooden floor surface; the middle trace is the synthetic floor that is produced by the SG window of ±10 samples; and the lower trace is the recovered (raw - synthetic floor) step sequence. A comparison of the three traces reveals that the recovered step sequence has the same amplitude as the raw data with an alternating high-low impulse sequence with a timing interval of 0.2 seconds. Given that human perception of loudness [8] is subjective, an objective measure would be the bandwidth of the impulse caused by the foot striking the floor. For this reason the acoustic signature are measured and used as a comparison with the hard shoe in section 3.2 Typically high impulses have an attack rise time of ~micro seconds, a sustain period of ~0.01seconds and decay a time of ~0.2 seconds to the zero-crossing point reference line. Figure 3 shows the dance percussion analysis (decoding) of the recovered step sequence discussed in Figure 2. The step sequence starts with the strike of the right toe (1) followed by the strike of the right heel (2) which has a reduced applied weight signature. The sequence continues with the toe (3) and heel (4) of the left foot and the completion of the first bar. From here the beats repeat to the end of the 8 bars and then repeat for second 8 bar sequence. The complete double sequence reveals 2 details of the male dancer. First, the dancer appears to reduce his applied weight in the beats of bars: 6, 7, and 8 bar of the first beats sequence. Second the dancer appears to be cognisant of the upping and coming end of the 8th bar: this is illustrated by the added etherise (weight) to the start of second 8 bar sequence.
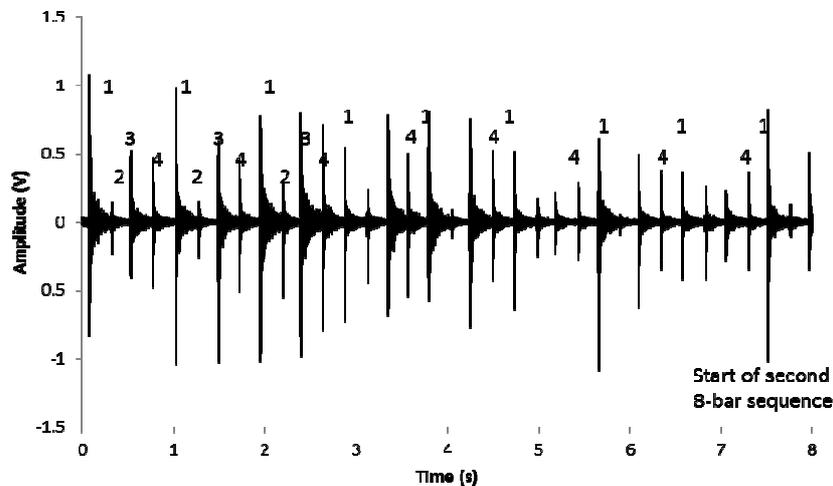

Figure 3: Decoding of the recovered male percussive impact sequence.

The required SG windowing to achieve minimum noise at the zero crossing point and linear time progression has been performed. The results of this analysis as a function floor type, male and female dancer and change to Irish light shoe for the female dancer is tabulated in table 1. The result shows that the

necessary window is a constant ±10 samples across the matrix. Within these datasets the impulses amplitudes and beat timing are also constant, apart from were a momentary change in the dancer's balance generate an increase noise around the beats, see figure 4. In this example the dancer establishes balance in the first few bars of the dance sequence. However the recaptured composure is not sufficient to match the rhythm displayed in figure 3.

Table 1. SG window matrix for floor, sex with bare feet and soft shoe

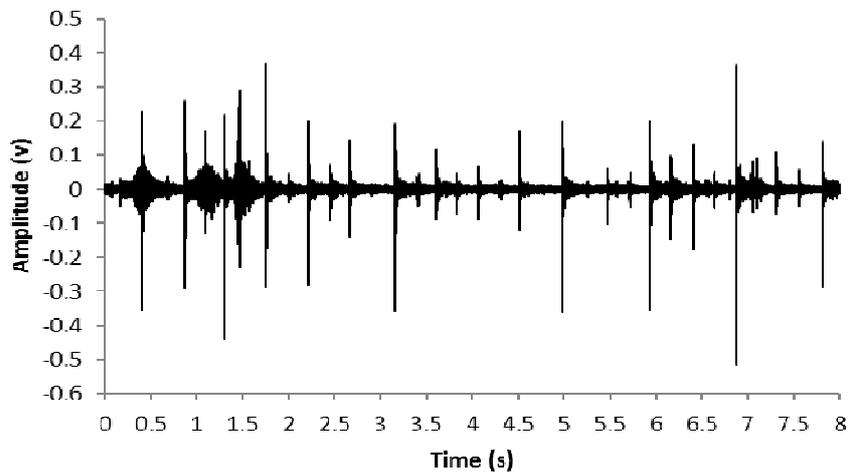| Dancer	Wooden floor bare feet	Title floor Bare feet	Wooden floors Soft shoes	Tile floor Soft shoes
Male dancer	±10	±10		
Female dancer	±10	±10	±10	±10

Figure 4: An example of dancer momentary weight imbalance.

3.2. Irish traditional step dance using a hard shoe

In this section a traditional step dance sequence is examined, again for two sequences. The acoustic signal is from the shoe impact on the floor producing a louder noise than that of the bare feet and Irish light shoe measurements, for this reason the microphone was placed some 3 meters away from the dancer and muffled. The tempo is set to produce a sequence of 8 bars two times over a 16 bar recording period. The sequence can be broken into 64 "beats" of equal duration. This 64 beats can be further broken into an 8 x 8 matrix. The dance sequence has 6 different types of percussive impacts and therefore 6 repeating sounds, the letters A, B, C, D, E & **F** (**F** being a heavy strike of the foot, and the silent gaps are represented with the letter P. In addition, letters that are underscored denote the left foot and the non-underscored letters denote the right foot. The full step sequence is shown in table 2. In table 2 the 2 letters **F** and **F** in the last line represents a double strike at the end of the first sequence. This is

followed by a pause of duration 3 beats before the sequence is repeated. The repeat sequence leads with the "A" sound, which is made with the ball of the left foot. The foot movements of the letters are listed as follows:

Table 2.

Line	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
1	A	B	C	D	E	P	**F**	P
2	A	B	C	D	E	P	**F**	P
3	A	B	C	D	A	B	C	D
4	A	B	C	D	E	P	**F**	P
5	A	B	C	D	E	P	F	P
6	A	B	C	D	E	P	**F**	P
7	A	B	C	D	A	B	C	D
8	E	P	**F**	P	**F**	P	P	P

A = Ball of foot
B = Forward stroke
C = Backwards stroke
D = Hop (landing on ball of foot)
E = Ball of foot (similar to A but with less weight)
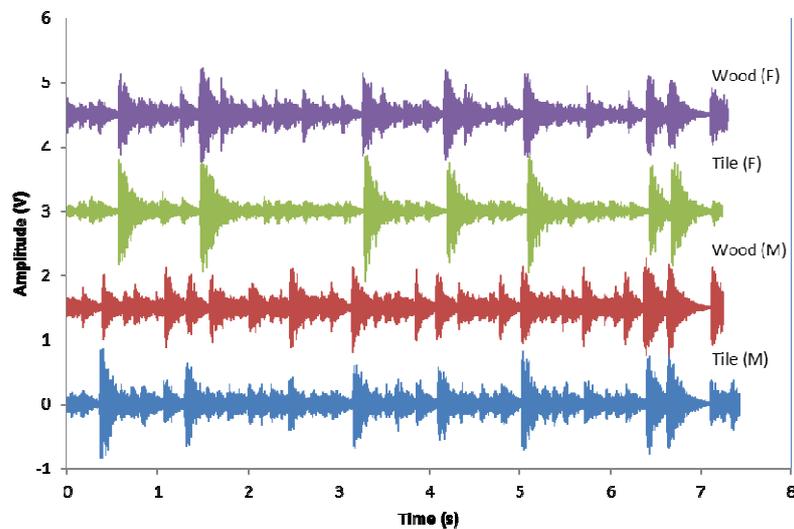F = Strike with whole foot

Figure 5: Comparison between male and female dancer performing the traditional Irish step dance on ceramic tile and wooden surface.

Four deconvolved acoustic time-series trace (synthetic floor removed: ±10 samples for the wooden floor and ± 22 sample points for the ceramic tile floor) of the traditional Irish step dance using the heavy shoes are shown in figure 5.

The traces are for both the female and male dancer on the ceramic tile and wooden floor, respectively. Each trace has been aligned to the double strike (**F**, **F**) and offset from each other to provide clear viewing. The traces provide an illustrative view of the individual step beats and their beat timing for both the wooden and ceramic tile floor. Note also the silent beats, in particular the triple silent gap at the end step sequence which allow the final F beat to exponentially decay before the start of the repeat step sequence. It is clear that there is a difference in emphasis on particular impacts for the two dancers. The female applies more weight to the F parts of the dance sequence when compared to the A, B, C, D & E sections of her sequence. The male dancer on the other hand delivers less variation in applied weight throughout his sequence. The result of this gives the female dancer the appearance of being lighter on her feet than the male, while the male appears louder overall. Figure 6 gives an analysis for the female dancer steps. In this sequence the F beats are stronger than the A beats as because of the area of the foot being used. However the A beats are stronger than the A beats, thus revealing a slight tendency to prefer the left foot. The figure also provides a qualitative comparison of loudness with the bare feet measurements. For example the sustain periods and decay periods are: typically 0.1 seconds and 0.5 seconds, respectively.
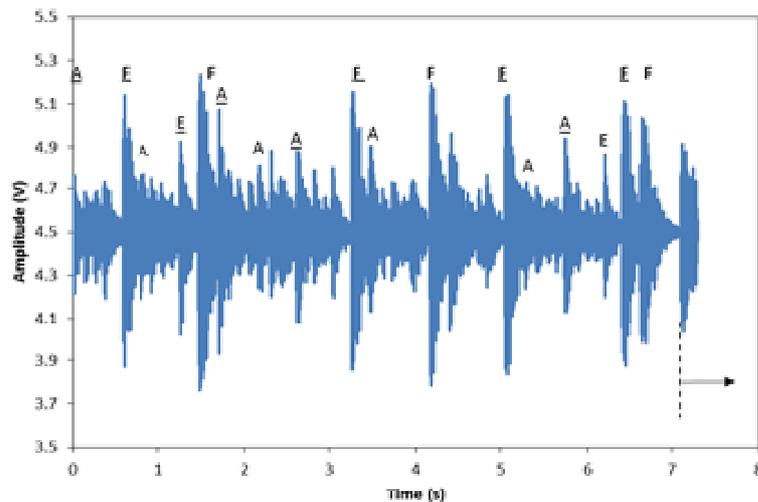

Figure 6: Percussive impact analysis of the female dancer performing the traditional Irish step on the wooden floor.

4. Conclusion

Acoustic recordings of two solo dancers performing the dance sequence and a traditional Irish step dance has been performed to the rhythm of 'Abe's Axe'. Shoe type (bare feet, Irish light shoes and Irish hard shoe) and floor type (ceramic tile and wooden floor) have been analysed. The analytical approach taken here has been to alter plasma diagnostic software that looks for periodic

signals in stochastic noise, to that of one that subtracts low frequency reverberations from high frequency quasi-periodic impulses synchronised to the dancer's feet impacting on a dance floor. The deconvolution of these processes is performed using a SG digital filter with a moving window, $k = \pm10$ for soft impact (bare feet and Irish light shoes) and $k = \pm10$ to ±22 for hard shoes.

The deconvolution process reveals that for bare feet and Irish light shoes the floor type does not have significant effect in the separation of the synthetic floor. A SG windowing of ±10 samples provides a clear deconvolution of the floor. For the hard shoe the ceramic tile and wooden floor respond differently to the foot impact: with wooden floor reverberating like an acoustic sounding board. Once the deconvolution process has been performed individual dance sequences within a rhythm can be identified and studied, including the recognition of left and right individual floor impacts. These software analysis attributes will make it possible to determine flaws during the performance of a dance piece. Discrepancies on dancers timing, applied weight, and overall dance sequence structure will be easily determined. It will also be possible to determine how a dancer performs using different equipment, for example a different pair of dance shoes and whether one shoe type suits a dancer over another. The software may help manufacturers of shoes to optimise the sound characteristics of different materials used in the making of the percussive plates as well as bench marking those currently on the market. In addition to Irish step dance, the step sequences in other distinctive percussive dances may be decoded, for example, but not exclusive to: the America Tap dance, Spanish Flamenco and the South America Tango.

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