Sampling the past: A tactile approach to interactive musical instrument exhibits in the heritage sector

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1. Abstract

In the last decade, the heritage sector has had to adapt to a shifting cultural landscape of public expectations and attitudes towards ownership and intellectual property. One way it has done this is to focus on each visitor's encounter and provide them with a sense of experiential authenticity.

There is a clear desire by the public to engage with music collections in this way, and a sound museological rationale for providing such access, but the approach raises particular curatorial problems, specifically how do we meaningfully balance access with the duty to preserve objects for future generations?

This paper charts the development of one such project. Based at Fenton House in Hampstead, and running since 2008, the project seeks to model digitally the keyboard instruments in the Benton Fletcher Collection and provide a dedicated interactive exhibit, which allows visitors to view all of the instruments in situ, and then play them through a custom-built two-manual MIDI controller with touch-screen interface.

We discuss the approach to modelling, which uses high-definition sampling, and highlight the strengths and weaknesses of the exhibit as it currently stands, with particular focus on its key shortcoming: at present, there is no way to effectively model the key feel of a historic keyboard instrument.

This issue is of profound importance, since the feel of any instrument is fundamental to its character, and shapes the way performers relate to it. The issue is further compounded if we are to consider a single dedicated keyboard as being the primary mode of interface for several instrument models of different classes, each with its own characteristic feel.

We conclude by proposing an outline solution to this problem, detailing early work on a real-time adaptive haptic keyboard interface that changes its action in response to sampled resistance curves, measured on a key-by-key basis from the original instruments.

2. Introduction

The heritage sector is one of the UK's prime assets. Heritage tourism contributes around £20.6 billion annually to the British economy, supplies an estimated 195,000 FTE jobs, and is recognised internationally as one of the UK's biggest draws as a visitor destination [1]. Such success is, of course, to be welcomed, but it brings challenges which impact upon the assets and resources on which the sector depends. Historic Scotland, for example, began monitoring and reviewing access to two of their key sites, Skara Brae and Maes Howe, part of the Heart of Neolithic Orkney UNESCO World Heritage site [2], using high-resolution photography to assess and evaluate the movement of stones within the sites and establish whether visitor numbers are causing serious damage to the monuments [3].

This tension, between access and preservation, has lain at the heart of curation for many years, and in order to strike a balance, reproductions have been used as part of museum strategy for over a century. However, since the advent of the digital age, when reproductions no longer need to be tangible, and particularly since the advent of laser scanning and 3D printing, the issue has become more nuanced.

In a pop-up lecture in November 2013 [4], Mona Hess, Research Assistant for 3D imaging and project co-ordinator of the Petrie Museum's 3D imaging project discussed the role of the museum replica, noting that not only do the 'reproduced objects allow the original object to be preserved and safe from close contact, but they also enable visitors to be more active and engaged participants' [4].

In a 2008 paper [5], Chungwei Lu also argues for the adoption of virtual reality techniques to broaden access to heritage artefacts and better balance the growing demand for access with the capacities of individual heritage sites.

However, as noted by Hess, [4], as artefacts are digitised and democratised, they enter into a new kind of contract and existence within social space, which in turn raises questions about ownership and authenticity. The broader question that is raised, then, is whether such an approach to virtualised heritage is an appropriate way for the public to engage and interact with their culture and heritage.

It has been argued that museums get their legitimacy through the authentication of, and by providing access to the artefacts that document and provide a history of evidence of people, their environments and their interactions [6]. As museums move into the digital age and embrace non-tangible and transient artefacts, they must consolidate their role against a backdrop of shifting attitudes towards intellectual property, stewardship and ownership, and an increasingly deprofessionalised culture of interpretation and commentary. One response to this has been to consider the museum as a means of accessing experiential authenticity.

Pine and Gilmour highlight three primary factors associated with authenticity in this context: the artefacts themselves; the edifices in which those artefacts are displayed, and the encounters or experiences of visitors to the museum. They argue that the public's encounters are always authentic, since experiences are an internal reaction to external events. The curation of the artefacts, however, is always artificial, rendering 'All museums… fake, fake, fake… and ontologically so.' [7]

Consider, for example, two different approaches to the curation and display of artefacts. On the one hand, museums may take a didactic approach, electing to display, for example, cases containing thematically-linked objects which chart development or illustrate change through time. On the other, museums may adopt a more experiential strategy, bringing together objects to form themed dioramas or living displays. Both museums can lay claim to the authenticity of their objects, but both approaches to curation introduce their own form of artifice. In the former, presenting objects in glass cases, removed from any sense of context is surely as inauthentic as bringing together objects from disparate sources to create a constructed reality for display.

We might also question Pine and Gilmour's assertion that the experience is always authentic – this surely depends on the nature of the experience and its centrality to the cultural encounter. Consider, for example, the currently-fashionable trend for 'historically-authentic' music performances, which feature performers in period dress, performing on instruments contemporaneous with the music. Of course, the costumes are modern replicas and the bows and many of the instruments of modern construction. The musicians will undoubtedly be performing in large, modern concert halls by electric candlelight, lest the audiences have to use the illuminated fire exits. And the audiences, unless they have made a supreme effort, will be wearing modern dress, and almost certainly will not have had to bear the stench of effluent-filled streets as they made their way to the auditorium. In these circumstances, each audient may well experience authentic sensations in the sense that they represent genuine emotional responses to what they see and hear, but in the broader sense it is difficult to reconcile this encounter with the notion of historical authenticity as billed.

Does this matter? Here, 'authenticity' is as much about positioning the performance and establishing a set of conventions and expectations as it is about creating something that is ostensibly 'real'. The audience are perfectly happy to suspend their disbelief and ignore the inconsistencies provided that they get an experiential flavour of both the spectacle and the nature of performance. In other words, this type of authenticity is given legitimacy by the audience, and it requires their active engagement in order to function fully.

The idea that engagement and interaction could lie at the heart of the museum experience perhaps should not come as any great surprise. As Marshall McLuhan famously noted "Anyone who tries to make a distinction between education and entertainment doesn't know the first thing about either." [8]. Nevertheless, the UK heritage sector has been slow to adopt experiential methods, due at least in part to

tensions between scholarship and entertainment. However, those cultural heritage attractions that have moved towards an experiential focus have succeeded in maintaining or even increasing visitor numbers in the face of adverse market conditions [9]. The case for focusing on experiential engagement [10] has been adopted by a growing number of heritage sites and internationally, the biggest rumble in the museum and heritage sector is reportedly “from the wall falling down between museums and theme parks.” [11]

3. The Benton Fletcher Collection

The Benton Fletcher Collection, maintained by the National Trust at Fenton House in Hampstead, is one such collection. Comprising some 19 instruments, including harpsichords, spinets, virginals, clavichords and pianos, which date from the 16th century, it was established by Major George Henry Benton Fletcher, a committed collector who – unusually for his time – advocated the value of playing early music on the instruments for which it was composed. Benton Fletcher made his instruments available to music societies and students for tuition, concerts and other cultural events, and, when the collection was gifted to the National Trust in 1937, he stipulated that the instruments should continue to be maintained for tuition and public performance [12].

The National Trust is fully committed to this purpose, and maintains a balance between Benton Fletcher's request that the instruments be played – music students can audition to use them, and visitors can attend ‘playing tours’ and concerts featuring the instruments – and their long-term preservation. However, because of limits on staffing and due to the fragility of many of the instruments in its charge, access is limited, and most visitors to the collection never get to hear or play them.

Of course, it is entirely understandable that the National Trust should err on the side of preservation. After all, let a few cohorts of eager schoolchildren loose on a working 16th Century Virginals, and the collection may not have a working 16th Century Virginals for very long.

Nevertheless, as discussed above, there is a clear and identifiable rationale for encouraging visitor engagement with music collections, particularly when they have been established and preserved as playing collections. A harpsichord, much like a vintage Ferrari or a basket-hilted broadsword represents an emotive fusion of form and function. It is as natural an impulse to press the keys of the harpsichord – regardless of musical talent – as it is to rev the engine of the Ferrari, or lift the broadsword to feel its weight and balance and better understand what it would be like to wield one in battle. If we present any of them on a plinth from behind a red velvet cord, we strip them of their function: they cease to be objects in their own right and become visually-compelling and ornate – but ultimately impractical – pieces of furniture.

It is this curatorial problem – the red velvet cord problem – that the Trust sought to address using high definition sound sampling as an enabling technology to provide a form of experiential access to the sound and playing characteristics of the instruments in the form of a standalone playable keyboard with touchscreen interface.

As a means of access, this approach has a number of distinct advantages. Separating the elements of the collection that are of primary concern from an experiential perspective – namely the sound and playing characteristics of the instruments – from those that present the biggest challenge to preservation – the fragile mechanisms – and embedding the sounds in robust, relatively cheap digital electronics allays many of the concerns about maintenance and preservation. Further, with digitally-controlled tuning, the digital instruments are not as susceptible as acoustic instruments to changes in temperature and humidity, and changes to tuning and temperament can be made with the flick of a switch (or the touch of an onscreen button) rather than by retuning an entire instrument, which may take hours. Most significantly of all, a single electronic keyboard can house sampled models of all of the instruments in the collection, allowing access to all of the instruments in the collection to those with impaired mobility: many of the instruments in the collection are displayed on the upper levels of Fenton House, which are inaccessible to those whose mobility is severely impaired.

Collectively, these arguments provided a strong rationale to investigate the use of music technology as a means of accessing cultural heritage, with a particular emphasis on the visitor experience and how it meets the needs of the 21st Century heritage tourist to be “entertained, stimulated, [and] emotionally and creatively challenged” [9].

4. Methods

The core methodological approach for this project dates back to 2003, and evolved in response to a production problem.

The author sought to create a set of archive recordings of the Panmure Music Collection [13], which comprises some 30 volumes of music, with 12 dating from before 1675. Much of the music is Scottish and English in origin, but the collection also includes 11 volumes of French music brought back to Scotland by James and Harie Maule between 1678 and 1683, and 6 volumes of opera scores and parts acquired by James Maule whilst in exile in Italy after the first Jacobite uprising in 1715. The manuscripts were rediscovered in the 1930s and placed by the Earl of Dalhousie in the trust of the National Library of Scotland, where they remain on permanent loan.

Much of the music had never before been committed to recording, and existed only in the form of archaic handwritten manuscripts. There is, of course, a world of difference between reading such a manuscript and experiencing a performance. In the same way that the transcript of a rousing and emotional speech cannot hope to

capture the passion of delivery, so too a musical score is at best an approximation of performance, and so to bring these compositions to life and appreciate them fully, it was necessary to transcribe the manuscripts and create a set of archive recordings.

A decision was made, then, to attempt to recreate the compositions as they would have sounded when originally performed some four hundred years ago. Thus, in addition to investigating and implementing such performance elements as playing technique, ornamentation and tuning, an instrument contemporary with the period was sought for performance.

Few keyboard instruments survive from the early-mid 17th century, and fewer still are in good playing condition. The project team were granted access to a Kirckman harpsichord dated 1776, which is held at Hospitalfield House in Arbroath by the Patrick Allan-Fraser of Hospitalfield Trust. Although the instrument was from a slightly later period than the manuscripts, there was evidence to suggest that it was of a similar design to those for which the keyboard music was written. It was of the right type – the Kirckmans were one of England's foremost manufacturers of harpsichords [12] – and it was in original playing condition. However, it was not suitable as a recording source. The soundboard, in particular, had warped and cracked, causing problems both with stability of tuning and with note articulation.

Figure 1 – Warping and cracking of the Kirckman's soundboard. The main damage can be seen up and to the left of the serial number, below the nut.

The response was to create a digital simulacrum of the instrument, using the hard-disk streaming technology that had been recently commercialised (see, for example, [14]), effectively using digital technology to overcome mechanical issues that would be costly to repair, both financially and curatorially.

It is important to note that any sampled instrument is fundamentally different from an acoustic instrument. The former is composed of a finite number of static snapshots, recorded at a particular moment, whereas the latter is, in principle, infinitely variable with a character and subtlety of expression that depends as much on the environmental conditions in which it is played as it does the manner of its performance. As such, it is impossible to create an exact digital duplicate of an acoustic instrument. However, by careful application of recording and editing techniques, it is possible to mask these digital artefacts, particularly in a performance context, to the extent that it is difficult under normal listening conditions to tell apart a recording of an acoustic instrument and a recording of a digital simulation of an acoustic instrument.

The initial phase of the project, then, focused on defining a methodological approach which focused on the analysis, recording and digital reconstruction of the harpsichord to create a playable digital model that sounded, in a performance

context, as close as possible to the original acoustic instrument. The method, then, did not so much focus on the technical approach to production or sample playback, but rather, the more conceptual approach of how we suggest realism in sampled instruments.

On the one hand, it seems reasonable that the more detail we include in a digital model, the more realistic or the more pleasing the outcome. And yet, as Masahiro Mori identified with the Uncanny Valley in the 1970s [15], and as Jentsch discussed in his 1906 essay 'On the Psychology of the Uncanny' [16], that idea of incremental improvement only holds true to a certain point. The closer we get to, for example, artificial human forms in robotics and 3D animation, the more we amplify the minute differences that distinguish the real from the simulated.

A similar phenomenon appears to hold with film, and has been highlighted with the 4k, 48Hz film format. Film 'works' because of 'persistence of vision': when a series of time-sampled images are shown to us quicker than about sixteen frames per second, the brain fuses them together to create the illusion of continuous motion [17]. Shooting at the industry-standard frame rate of 24 frames-per-second (fps), along with the motion blur that is introduced and the limited depth of field helps to create a cinematic look and feel, and good directors and directors of photography will use this 'fuzziness' as an asset; staging shots very carefully to include only those elements that contribute to the story, and – just as importantly – exclude those that detract from it.

So if 24 fps is good, it stands to reason that 48 fps in high-definition must be better, and yet it seems that the added clarity which results from the new format might actually detract from the viewing experience by distancing the viewer from the diegesis. The critical response to the Hobbit: An Unexpected Journey [18], for example, has been fairly unequivocal. Dana Stevens of Slate magazine described the viewing experience as like watching the Teletubbies or a daytime soap, primarily because the 'wildly expensive visual technology paradoxically conspires to make everything else in the film look cheap', highlighting any 'imperfection or note of artifice in the costumes or sets' [19].

The investigation at this stage, then, focused on those aural cues that are necessary and sufficient to trick the ear into thinking that it is listening to an acoustic performance. The solution, it transpired, is very much context-dependent, and best specified as a production approach. The approach is both analytical, in that it first focuses on a detailed analysis of the instrument and those idiosyncrasies that give it its unique character and sound before selecting a recording strategy that allows the samplist to capture those sound-producing elements independently, and reflective, in that the recording and editing chain must be carried out with one eye on the end user and the other on a series of reference recordings of the original instrument to ensure that the individual layers of the digital instrument combine to provide a listening experience that is close to the original.

Such elements as instrument tone are relatively easy to record, but special care must be taken with other subtler elements of the sound, such as the transient attacks, which can vary depending on the velocity of the note, and which are important in simulating fast-repeating notes without 'machine-gunning' – an artificial mechanical-sounding effect that occurs when a small number of note samples are played back in quick succession; key release noise, which is release-velocity dependent and very important in creating the illusion of realism; sympathetic resonance and mechanical noise. The precise makeup of the sampled instrument will necessarily vary depending on the particular characteristics that make up its sound and the prominence of each, but as with a good Director of Photography, who will include only enough visual detail within each frame of a film, using depth of field and motion blur to bring key elements of the frame into focus and push others into the background, so too a samplist looking to recreate the specific sound of an instrument will first analyse the component parts of its sound, and construct the digital model so that those which are most prominent feature as the key aural cues, whilst the others provide layers of supporting detail.

The resulting instrument was used as the basis for a series of instrumental recordings [20], and the process and outputs were exhibited at an international exhibition of digital heritage and preservation in Belgium in 2005 [21].

This, then, provided the main means of capturing and modelling the instruments in the Benton Fletcher Collection, which served as the central sound source for a dedicated interactive exhibit at Fenton House, allowing visitors to the collection to access and play the instruments in the collection with no risk of damage to the originals.

It was agreed with the National Trust that the project would proceed using an iterative design approach over a number of years, using a combination of expert and non-expert user testing to provide end-user feedback. All aspects of the exhibit would be investigated, including the physical elements of the interface (cabinet design, point of interface, control method and physical layout); the software interface; sound quality and fitness-for-purpose. Expert feedback was provided by Mimi Waitzman, who served as curator-conservator of the collection from 1984 until 2012. Non-expert feedback was gathered from visitors to the collection using observation, interviews and a dedicated comments book.

5. Summary of results

The operational phase of the National Trust project ran between 2008 and 2013, and featured four iterations of the modelling and refinement process. The instruments were analysed and production strategies were agreed upon with the expert user in advance of recording. Recording of the instruments took place in situ immediately after the property had been closed to visitors for the season and its objects prepared for the winter – typically late November or early December. The recordings were edited and prepared, ready for installation at Fenton House in April/May the following year for the new visitor season.

The digital instrument is controlled using an embedded interface, displayed on a 17-inch commercial touchscreen monitor. Selecting an instrument navigates to a display page, which presents detailed information about the selected instrument, loads the soundset associated with that instrument, including all performance variations, and presents the user with a set of touchscreen controls which allows real-time control of these performance variations.

The control surface is a two-manual MIDI keyboard, which uses two semi-weighted single-manual MIDI keyboards, with modified keybeds and scan circuits to replicate the layout of the harpsichord keyboard, commonly, five-octaves from F to F, with no F♯ in the bottom octave. Keyboards from the collection whose span is shorter than five octaves are accommodated by leaving some keys in the keyboard unmapped, and short octaves – a means of assigning the most common notes to the bottom octave of a keyboard to extend its range [22] – by a simple remapping of the root pitch. Broken octaves, a variant of the split octave which increased the bass range by means of split keys [22] required more of a compromise, since there was no cost effective means of producing a split-key electronic keybed, and it was agreed with the expert user that the exhibit would use a foot-pedal as a means of real-time keyswitching, this being both a natural performance gesture in keyboard performance, but also very much in keeping with the notion of the harpsichord machine stop, a foot-operated pedal that was used to mechanically alter elements of the instrument's set up in real time [22].

The MIDI keyboard acts as a front-end interface for an embedded PC running the control software and handling sample playback. All of the componentry is housed within a bespoke transparent Perspex casing, which allows visitors to see all of the electronics, making a display feature of the digital nature of the instrument and properly delineating it from the other instruments within the collection.

The digital instrument was placed on display in the garden room on the ground floor of the house, this being one of the most accessible areas of the property, and is positioned alongside two other instruments from the collection.

Figure 2 – The two-manual MIDI interface for the digital harpsichord.

User data on the digital instrument were collected continuously following installation. Both groups, that is, both expert and non-expert users, suggested design changes throughout the project run.

The expert user primarily provided feedback on the detail of the models, in particular highlighting a number of minor errors in functionality and tuning, which were modified in subsequent iterations.

The non-expert group overwhelmingly supported the idea of virtual access to the instruments, finding the approach both novel and engaging. Suggestions for enhancements included a dedicated music stand with examples of sheet music, and pre-recorded examples of the instruments for auditioning. Interestingly, ‘sonic realism’ appeared to be less important to those surveyed than having the digital models in situ alongside the original instruments, and carrying the endorsement of the National Trust itself. Of course, this does not necessarily suggest a relaxing of the aim of aural transparency in the recording process, but does perhaps give us an insight into the conditions under which visitors will willingly suspend their disbelief and ascribe authenticity to the experience of playing the sampled instruments.

One issue reported by both groups, however, was the keyboard interface itself. As a basic means of interface, using commercially-available keyboards has its merits. The MIDI keybeds are cheap, robust and functionally similar to the harpsichord. However, from the perspective of providing an experiential sense of interacting with a historical keyboard it is poor. Several of the visitors surveyed commented on the feel of the instrument, and the expert user in particular noted that she felt detached from the sound source because the key action lacked feel. Of course, this was not the primary focus for the project, which was concerned with accurately modelling the sound of the instruments in the collection, and so this aspect of interface was compromised both by design and by budget. However, given the context in which the digital instrument is intended to be used, and the associated experiential authenticity that the context demands, it is worth considering the problem in more detail.

The feel of an acoustic instrument is of fundamental importance to musicians, who train for many years to achieve the fine motor control necessary to coax the full range of expression from their instruments. Any performance is the result of a complex dynamical system which incorporates gestural input from the player, the mechanics of the instrument, and the resonances and natural amplification that its body provides. However, there is no straightforward mechanical solution to this problem. There is no commercially-available keybed which will replicate the feel of an antique harpsichord, and, although it would be possible to fabricate a 'dummy' mechanical mechanism, similar to the piano mechanisms used by, for example, Kawai, Roland and Yamaha in their high-end digital instruments, the approach would be prohibitively expensive and does not represent the optimal solution for two reasons.

Firstly, although mechanical key actions can be engineered to provide an accurate key feel for a particular instrument, a grand piano say, that same action will be rendered inappropriate as soon as a different soundset is loaded. For the purposes of the installation, which must replicate several different types of keyboard instrument with related but very different key mechanisms, a single mechanical action would provide an appropriate key feel in only a limited number of situations.

Secondly, from a heritage perspective, where, as we have discussed, the aim is to achieve a form of 'experiential authenticity', there is also a much more stringent threshold than 'good enough' – it is not sufficient to create a mechanism that is generically appropriate to the instrument class, but to create, on a key-by-key basis, the precise mechanical feel of an entire keyboard.

6. Conclusions and future work

The primary conclusion to be drawn from this phase of the project, then, is that there is a clear and identifiable desire for the public to interact with the historic keyboards of the Benton Fletcher collection using playable digital models. In line with the three factors affecting heritage authenticity discussed by Pine and Gilmour, we observe that despite the artifice introduced by the sampling process,

and the deliberate delineation of the digital instrument from the originals, visitors were still prepared to accept the experience of playing the instruments mediated through digital copies as both worthwhile and authentic given that the edifice which supported the interaction provided an appropriate and authentic context to the encounter. Indeed, the design of the digital instrument, which makes a feature of its artifice, may play a significant role in this, since it sets out clearly the nature of the object and its relation to the artefacts to which it relates, and which surround it: it is true to itself and it is what it says it is [7].

Surprisingly, the perceived realism of the digital instrument was not the primary concern of the non-expert users, although it was for the expert user. Further investigation is needed to determine the reason for this – it may be that the digital instrument exceeds some threshold of perceived realism which may be established in part by individual expectation or experience; it may be that the contextual factors outlined above over-ride the requirement for objective realism, or it may be that the novelty of being able to interact with instruments that had previously been out-of-bounds offsets critical judgement – the intensity of the experience overriding the purpose [23].

A more pressing result, however, is the feedback which highlights the psychophysical limitations of the current MIDI keybeds as the primary point of interface between the musician and the instrument, with both expert and non-expert users highlighting a sense of disconnect between the physical interface and the sound source – the difference between playing ‘on’ and playing ‘with’ the instrument.

The problem is fundamentally an engineering problem, and this shapes the next phase of development: the proposed creation of a haptic keyboard, which will use sampled displacement-force curves to control linear voice-coil actuators to provide positionally-sensitive real-time force feedback at point-of-contact. This represents a development of earlier work by Brent Gillespie at Stanford University, whose Touchback keyboard used simplified mathematical models of a grand piano action to similar effect.

Early prototypes of Gillespie’s keyboard used motors originally designed for large disk drives, which suffered from high intertia, but Gillespie was able to overcome this restriction and build a six-key prototype using optical encoders, tachometers and strain gauges to measure the position of the keys and the force applied by the performer [24].

There are a few important differences between the actions of the piano and harpsichord, which should be considered with regard to the viability of this approach. Unlike the piano, which uses a complex series of levers and escapements to regulate its action and decouple the finger from the hammer during the point of contact with the string, the harpsichord action is much more linear and the player controls contact through touch throughout the full cycle of each note event, including release and damping.

Each key is a relatively simple lever, pivoted on a balance pin which sits on a rail which runs beneath the keybed. At the back end of each key is a jack, at the top of which is a hinged plectrum and damping cloth. As such, each key has a relatively free movement and low inertia during the initial portion of displacement until the plectrum makes contact with the string. The resistive force of the string becomes the dominant force at the point of contact, but is fairly transient, and provides a low resistive force. On release, the plectrum again makes contact with the string, but the hinge allows the plectrum to move back, and the jack will fall naturally under gravity. This second strike causes a characteristic 'chirp' before the damping cloth mutes the string. A skilled player will use key feel to modulate the release of the key to control this second strike, and minimise the effect of the mechanical noise, particularly at the end of phrases.

We propose to investigate the viability and tenability of this approach by creating a small-compass haptic keyboard which simulates the key response of a specific acoustic instrument, and which will draw on the experience of our expert user to evaluate the results and feed back into the iterative design process.

As a multidisciplinary project, we will use a range of results and methods drawn from different fields of study, and so although the overall methodological approach is based on an iterative design process, a key outcome of the project will be to develop specific methods applicable to the various stages of the project, but in particular:

- To measure and characterise the force-displacement characteristics of a specific harpsichord keyboard, and

- To undertake a comparative analysis to gauge the suitability of components for modelling the harpsichord mechanism in terms of inertia, fine control and response time, and generalise these findings for other keyed instruments, primarily spinets, virginals and clavichords, which exhibit some commonality of mechanism.

The ultimate aim of the project, however, will be to build a working prototype which will be subject to both quantitative and qualitative measures to evaluate both the physical and perceptual aspects of haptic feedback as a means of providing player interface.

In summary, we propose an incremental development of an existing approach in order to address a problem of interface that was identified through a systematic approach to incremental design and user-testing. The rationale that underpins its use in a heritage context, and the platform that this affords us for testing and development is a direct consequence of the knowledge exchange that has resulted from partnership with the National Trust and the Patrick Allan-Fraser of Hospitalfield Trust, and it is through further development of these key relationships, drawing upon a broad collaborative expertise, that we plan to develop a solution. It is envisaged that the solution will provide a bespoke method of interface, specifically tailored to the needs of musical instrument display, which will further

engage those who wish to experience first-hand the musical heritage that the UK has to offer.

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