The Quarterstaff, a Gestural Sensor Instrument

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ABSTRACT

This article describes the motivations and reflections that led to the development of a gestural sensor instrument called the Quarterstaff. In an iterative design and fabrication process, several versions of this interface were built, tested and evaluated in performances. A detailed explanation of the design choices concerning the shape but also the sensing capabilities of the instrument illustrates the emphasis on establishing an 'enactive' instrumental relationship. A musical practice for this type of instrument is shown by discussing the methods used in the exploration of the gestural potential of the interface and the strategies deployed for the development of mappings and compositions. Finally, to gain more information about how this instrument compares with similar designs, two dimension-space analyses are made that show a clear relationship to instruments that precede the Quarterstaff.

Keywords

Gestural sensor interface, instrument design, body-object relation, composition and performance practice, dimension space analysis

1. INTRODUCTION

The question of the interface lies at the heart of many NIME developments, as its place in the acronym of this conference shows. The principal issues that these new interfaces try to address is to come up with a conclusive solution for a specific performance style, interaction type or control of a musical algorithm. Part of the motivation for NIME research lies in the exploration of the potential of new sensing technologies, in order to render them fruitful for music performance, applications they are usually not originally designed for. Another motivation is the investigation into the perceptual, gestural, conceptual and even epistemological aspects of the practice of new interfaces. And the question about the bridge between physical and symbolic (Or to put it differently, the abstract electronic black-box) domains takes centre stage and is addressed through the vast topic of mappings and cross-domain translations.

The Quarterstaff project arose out of the determination that some of the fundamental questions about the value of a NIME (new instrument or new interface) didn't primarily lie on the technical level, but more centrally in the musical and even fundamentally physical and embodied practice exercised through the instrument. In order be able to operate within these domains, the necessity to have a concrete sensor-carrying instrument with a clearly constrained gestural scope became apparent. The project evolved into a process of investigation into the shape, dimensions (both physical and affordance-wise), sensing modalities, and integration of an instrument with software. And even more fundamentally an inquiry into the conceptual aspects of embodiment arising from a sensor-based digital musical instrument performance. After building several versions of the interface, the questions of the gestural potential of the instrument, the composition strategies, but particularly the performance using the interfaces became urgent. The performance on stage helped to focus the design, building, testing and reflection about the Quarterstaff instrument and serves as the final goal of this process, its crystallisation point and validation context.

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2. BACKGROUND

The quarterstaff was a two handed medieval fighting stick for commoners and later a training staff for two-handed sword-fighting [20]. The naming of the instrument seems to be somewhat misleading, but it is actually not completely off the mark. The two handed grip and the staff shape represent a shared attribute of the interface with its namesake.

But more importantly, the central idea of this investigation is that the insight arising from laptop performance that we need ***objects*** in our hands in order to feel a coherent instrumental relationship leading from our musical intentions and sense of agency to our instrumental actions and their sonic results. Arguing from a perspective of cognitive sciences and 'enactive' philosophy, Gallagher states that "object perception involves an experience that is *directed at* the object. [...] To perceive involves the ability to pick something out, to identify it as an object or as a state of affairs in some minimal sense" [7, p.55]. This fundamental cognitive principle can be found expressed in any tool – and weapon – usage that has shaped our relationship with the world throughout human evolution. What is more relevant to music performance, however, is that through traditional musical training the integration of a *physical* musical instrument into the body-schema [8, p.26]. This is what ultimately gives the performer a pre-reflective, almost autonomous capacity to perform complex bodily and auditory adaptations during playing. For this integration to succeed, a number of sensori-motor patterns need to be imprinted into the body's muscular memory, into the somatic and kinaesthetic and proprioceptive senses [3]. Since the adaptive feedback concerning both the auditive and the tactile/kinaesthetic loops [9] continuously affect the performance at a pre-reflective level, the body takes over most of the control, running in a mode of performative awareness [8, p.74]. If "the first element of broad self-consciousness that somatic proprioception provides is an awareness of the limits of the body" [2, p.149] then the physical contact with the instrument provides a pre-reflective self-awareness that constitutes an element of the sense of agency and generates a clear context for the bodily awareness. This awareness is a necessary condition for instinctive and fluent playing of a musical instrument.

Another aspect that is central in this inquiry is the question about the influence of the shape and size of a interface on the gestural repertoire and more specifically on the dynamic qualities of the gestures. Depending on the proportion of the object in relation with the hand, the arm and the entire body of the performer, the gestural space covered by the object will either be in the domain of the hand-radius, a lower arm and possibly torso-sized radius or a peri-personal sphere with dimensions corresponding to the size of the entire body. As an example, the gestural amplitude of the interacting with a traditional game controller is occurring in the finger-size domain – and if the controller is motion-enabled the amplitude might increase to that of the hand-forearm-elbow-radius domain.

Finally, a question that a NIME almost always has to address, is the fact that any instrument or interface that doesn't produce sound by itself but serves to control sound production will function at a metaphorical level. This poses questions about what types of metaphors are in play intrinsically – given through the shape of the object – the affordances of the interface and the interaction models built into the object [10]. By finding out what those are, it should become possible to relate these metaphors in a more specific way with what the instrument actually offers.

Within the development cycles of the Quarterstaff project a number of these questions were raised and some solutions that were were found during the application in real musical development and performance situations will be described in this article.

3. CONTEXT

In the NIME community a number of instruments have been shown that may have served directly or indirectly as inspiration or point of reference for this instrument. They all share a strong relation to natural gestures and a focus on (bi-)manual handling. The first of these are the MO – Modular Musical Objects – by IRCAM, that have become a highly refined product with a wide palette of applications [4, 17]. With a comparable size and capabilities the sense-stage nodes were developed for performing arts stage situations, where multi-node sensing systems could be applied [1]. Two student projects from NIME courses need to be mentioned here. 'El Lechero' by August Black, was presented as an accordion-like interface with dual axes and was developed in the conetxt of a NIME course at UCSB [14]. The 'Kalichord' is an interface developed by D. Schelssinger at CCRMA which mixes an accordion grip and posture with plucked string physical modelling [19]. Conceived and designed with more of a performance-context in mind, an important reference that will be discussed later on, is the T-Stick by Joe Malloch from McGill [13]. This interface was mainly designed as a performance interface; a number of different composers and performers have developed a repertoire and practice based on this instrument. Another interface that was designed with a strong focus on music performance and whose handling resembles a traditional keyed, hand-held instrument is the 'Sormina' by Räisänen [16]. Two more projects belong in this overview, even if they are more related to a direct traditional instrument heritage. The first instrument is the Karlax by Tom Mays[1] that mixes saxophone grip and fingering style with motion sensing and a central split with a rotational axis. The second instrument is the Eigenharp[2], an interface that offers a large array of illuminated touch sensitive keys arranged in a guitar-like gridded geometry. It is worn like a guitar on a strap or on a stand directly in front of the body. Both of these interfaces are produced and sold commercially and used in pedagogical situations and live-performance settings by professional musicians who don't necessarily subscribe to the NIME discourse. Finally, one last reference has to be mentioned, even if it has been eclipsed by more recent developments in its domain. It is the Nintendo Wii controller, a motion-enabled game-controller that – for a while at least – epitomised everything a hand-held controller could be.[3]

4. THE INSTRUMENT

A number of versions of the instrument were built using different construction techniques. During this iterative process the different generations of the instrument didn't fundamentally change. The main changes were in size and in the addition or omission of sensing capabilities. Great care was taken to maintain all versions in a functional state (i.e. fully playable) and to back-propagate new sensors to older versions. This is an important element of this investigation and needed in order to maintain a set of commonalities against which the differences are compared. The design process took place in a rather loose fashion, refining and reflecting on the qualities of a version before starting the next iteration. This might have cost the project more time but offered the benefit of being able to evaluate each design iteration in a real-life performance situation.

4.1 Interaction concepts

The basic model for this instrument is holding a staff in the hand. Through a very clear and simple shape, the object helps to focus on the exploration of gestures and permits basic instrumental and control actions. The interaction model or gestural image/metaphor is one wielding a tool, such a using a shovel or axe, but might also evoke gestures from sword-training or even music conducting with a staff. Feedback from audience members indicates that the performance with the Quarterstaff resembles the wielding of a magic wand or specific movements from martial arts. This indicates that there are no culturally accepted and recognised templates for these types of action patterns. Through abstract gestures that stay clearly anchored in the physical dimensions and characteristics of the interface, the development of an idiom for performing becomes possible. In addition to the motion sensing capabilities, the interface offers a series of discrete sensing elements that can be perceived and therefore intuitively used as simple control elements. The mixture between gestures and direct discrete actions enables the usage of the Quarterstaff as fully-featured autonomous instrument on stage, something which would be difficult with just the motion sensing. By making the staff wireless and easily rechargeable, and providing a limited set of interaction modes, the technological nature of its manufacture fades into the background.

In order to leverage our tactile sense and dexterity, sensors are added on the outside of the staff, that present interaction surfaces for the fingers. The staff is built for

[1]see `http://www.karlax.com`
[2]see `http://www.eigenlabs.com`
[3]see `http://www.nintendo.com/wii`

bi-manual operation without a fixed grip. Depending on the playing situation the grip can change. The kinaesthetic sense or emphasis on tactile and proprioceptive cues is reinforced by the separation of the staff into two mechanically linked halves.

In comparison with the Quarterstaff the T-stick project on the one hand explored similar aspects of this form-factor and gestural space. It shares the bimanual grip and motion sensing capabilities in a similar size staff but offers only one other mode of interaction through a 'capacitive keyboard' covering the entire length of the stick. The Karlax interface on the other hand shares the bi-manual grip and the central split with a rotational axis. Apart from also being wireless and motion sensing it offers a multitude of keys and buttons. Its metaphor, however, is clearly based on a saxophone shape and posture. The keys and buttons are arranged in such a way as to offer a trained saxophone player an almost seamless path to applying their instrumental skills to this instrument. The size and the grip constraints, however, don't seem to afford a large motion amplitude. Judging from the video documentation, which shows a variety of performers and a dancer, the instrument is held in a constrained position in front of the torso and the motion range covers the rotational space of the forearm-elbow.

4.2 Physical Properties

Digital fabrication processes were used to shape the object itself. The first two version were built using laser-cut plywood and were assembled in a rib and spar skeleton, that was covered in plywood. The third version and future editions are fabricated using subtractive CNC-milling from a solid block of wood. Each half of the instrument is split into two shells that fit together to form the hollow staff. Some other fittings are hand-milled or laser-cut, especially the parts holding the central axis (see Figure 1 and Figure 2)

Figure 1: The third version of the Quarterstaff. Left: the milled interior and the carbon tube forming the axis. Centre: the entire instrument. Right: a close-up view of the central section and the miniature 5-way switch.

The first version has a dimension of 46 cm in length by 50 mm width and 25 mm height. The second edition grew to have a length of 105 cm by 50 mm width and 25 mm height. The third massive version reaches a length of 76 cm by 50 mm width and 30 mm height. Due to the size constraints of the electronics-compartments all the staves are hollow throughout and open along a longitudinal seam. For that reason their weight does not correspond to their size. The first two versions are varnished in clear and in black, respectively, whereas the third version uses an oil and wax finish to maintain the tactile feeling of wood.

The dimensions of the staff are tailored to elements of the anatomy of the hand and arm. The cross-section was chosen to fit into the space encircled by the index finger and thumb. This element of the shape has proven to fit fairly accurately and will only be altered in future versions to offer tactile markers through changes in diameter.

The main experimentation with the shape was done by altering the length of the staff. The first design started with a short length (46 cm) that corresponds more or less to the size of two elements tailored to the stretch of a hand. After performing with this version on a few occasions, two issues came to attention that were addressed in the following version. The size of the entire staff is too short, leading to a gestural space that doesn't exceed easily the forearm sized hemisphere in front of the torso. And the instrument is too light, and therefore doesn't convey the kinaesthetic feeling of wielding the actual object of its size. This cognitive dissonance is a hinderance in the development of a natural gesture idiom.

The second version of the instrument tries to correct the length by more than doubling the length. In this design the weight becomes more appropriate to its size. The proportions of the instrument are slimmer and recall a sword rather than a stick. The grip and handling of the staff remain appropriate to the hand size. However, the length of 105 cm now exceeds the full arm length (which is roughly 76 cm for the authors right arm) and poses problems when swinging the staff in circular arcs towards to torso. Yet the large size also has its advantages, especially with regards to speed. It becomes possible to swing the full staff at higher speeds thanks to inertia and extended radius. Since the motion sensors are located in the tip of the staff this increases the dynamic range of acceleration and rotation values in a noticeable way.

The third version of the instrument is adjusted in size again. This time its dimensions are chosen to correspond to the actual arm-length (76 cm) and fall in between the sizes of the first and second versions. The radii of swinging arcs are reduced, but now they no longer produce collisions with torso and upper arms. The range of motion clearly leaves the hemisphere in front of the torso and expands to include a sphere spanning from the knees to above the head. An additional benefit is that the shoulders now become much more active, thus providing a greater freedom to move and thereby enrich the gesture repertoire used during performance.

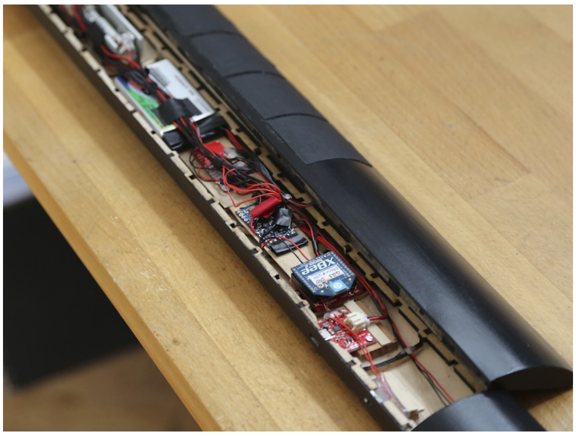

Figure 2: Second version of the Quarterstaff, details of its construction and placement of the electronic components.

4.3 Electronics

The technological aspects of an instrument used to account for a large part of the challenges of designing a digital musical instrument. Through the widespread availability of electronics for DIY projects and the arrival of open-source hardware platforms such as Arduino this has thankfully lost its urgency. The threshold for completing fully functional, persistent and reliable electronics that include such characteristics as wireless data links, integrated charging of high-density batteries and access to sensors that communicate in digital formats has been lowered considerably.

The electronics of the Quarterstaff interface are all commodity products and can be purchased through specialised commercial suppliers.[4]

The heart of the system is an Arduino Mini Pro with an Atmega-328P micro-controller running at 8 MHz.[5] It sends its output data through a pair of Xbee modules, that form a transparent wireless serial link at 56700 Baud (this is constrained by the clock rate of the MCU). The entire sensor data is transmitted in packets of 34 bytes at a rate of roughly 100 Hz with a latency of approximately 5 ms.

The motion sensor provides three dimensional values for acceleration (11 bit resolution), rotation (16 bit resolution) and magnetic field (12 bit resolution). The eight force sensing resistor pads and the central axis potentiometer are multiplexed into one analog input pin that converts A-to-D at 10 bit resolution. Lastly, a small 5-way switch is connected to five digital pins and provides discrete switching capabilities.

The battery is a 1000 mAh LiPo that provides the entire system with 3.3 V. It is connected to a charging circuit, that allows it to be charged through a standard micro-USB cable. (see Figure 2 for a typical hand-soldered configuration: electronic components from bottom to top: power switch, charging circuit, Xbee wireless transmission unit, Arduino MCU, multiplexer, LiPo Battery and (blurry) axis potentiometer. On the top shell are four of the eight interlink FSRs painted black.)

4.4 Software

On the host computer a proxy server software is used, that translates the serial data stream and re-transmits it onto the network bus (locally or remote). A benefit from using this approach is that it isolates the sometimes fragile serial port from the sound processing software. In addition it also pre-processes the sensor data, reconstructs higher resolution values, normalises the values to unity ranges and generally scales, filters and combines the information. Finally it puts labels on the streams and sends them on with a coherent namespace through the OSC protocol. The software is coded in openFrameworks[6] and is designed to provide a highly stable 'fire-and-forget' solution.

The mapping and sound parts that make an interface into a full-fledge digital musical instrument are discussed in the next section, since they also form an integral part of the musical development processes.

5. THE MUSICAL PRACTICE

Before the development process for the Quarterstaff had reached a point where it became useable, the question of how to compose and perform it was already present. Instead of speculating, a series of sketches were designed that allowed the exploration of individual features of the instrument. Needless to say, these sketches could show neither the potential nor limitations of the instrument. Therefore, and as soon as it was ready, the instrument was used in a live setting. The first version was used in a number of concerts and always used to perform the same piece. This act of rehearsing and practising served not just for the musical refinement of the performances but also to establish a familiarity with the instrument. The design process described earlier was directly informed by the performances.

5.1 Exploring the Gestural Potential

The composition process for a piece using an instrument such as the Quarterstaff has to approach the sonic materials from two sides. On the one hand a choice of materials and processes is made and on the other hand the gestures, intensities and actions needed to embody the piece are assembled. In an interrelated manner, the exploration of the gestural potential influences the compositional choices. For example, the formulation of a gesture, such an arc starting at the top left of the body space swinging across the shoulder to the lower right, immediately evokes a slicing defensive gesture. This poses the question, what sound gestalt could correspond to the gesture (see Figure 3. the fourth image shows the beginning of that gesture). In a cyclical, iterative process, a collection of such gestures come together, providing metaphorical meaning and guidance for the composition of sonic shape of the piece.

5.2 Gesture Extraction and Mapping

The challenge in working with such categories and gesture characteristics is how to capture these in sensor-based data streams. One solution is to use a simple posture identification that, combined with the features of streams, such a movement vectors, helps determine what action or gesture took place. This pattern matching is a crude precursor for machine learning algorithms, such as the gesture follower [4], but can provide a robust modular set of templates to be combined in a number of gestures [5]. A simple use-case of these combinations could be the subdivision of the peri-personal space into quadrants, determined by the magnetometer-values (compass-bearing). A stroke that is recognised through an acceleration peak located within a specific quadrant can be mapped to one thing, while the same stroke in a different direction will mean something else. Apart from having a flexible mapping system, which cleanly decouples gestures and control actions from a specific sonic assignment, the most important aspect of mapping is to have a set of abstract gestures, that can be expressed in many combination with the interface [18]. These abstract gestures represent the affordance space of the integrated digital musical instrument, which is the combination of the interface, the mapping and the sound processes. Another important feature of the mapping is "a tight connection between a body movement and change in an auditory feature" [21]. Machine learning and pattern recognition algorithms have the problem of lagging behind the immediate action. This lag breaks the pre-reflective link established through the kinaesthetic, somatic and proprioceptive engagement with the interface. The space of this article doesn't permit to go into the implementations and models of machine learning and mappings. Future work will address these aspects of the musical practice with this interface.

5.3 Composing versus Performance

An essential aspect of composing for this type of gestural interface is that since the instrument builds heavily on establishing a tactile, kinaesthetic and proprioceptive relationship with the performer on a corporeal level, the only proper way of experiencing the affordances of the interface

[4]see `http://www.sparkfun.com`
[5]see `http://www.arduino.cc`
[6]see `http://www.openframeworks.cc`

Figure 3: The author performing with the Quarterstaff at the Sound Reasons festival, Delhi, November 2012. Note the different grips and range of gestures.

is by performing with it. Therefore an experiential approach to composition is necessary. Explorative playing with simple sonic materials has proven to be a valid strategy to discover gestures and ways of handling the instrument.

The initiatives by both the T-stick and the Karlax composers to collaboratively work on a classification of gestures and establishing either a notation or a terminology for these instruments seems to offer a way forward in this type of instrumental practice.

6. DIMENSION SPACE ANALYSIS

In order to compare the Quarterstaff to other interfaces and instruments of its type, the dimension space by Birnbaum, Wanderley et al. [6] is applied (see Figure 4). [7]

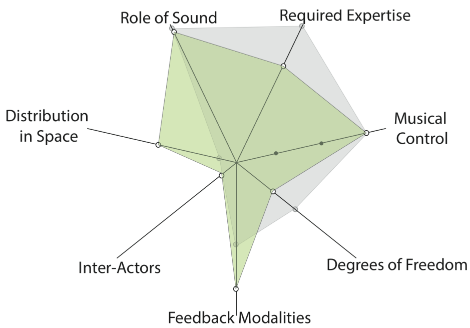

Figure 4: The Quarterstaff placed in the seven dimensional space proposed Birnbaum et al. In comparison the values for 'the Hands' by Waisvisz are underlaid.

– On the *Required Expertise* axis the Quarterstaff doesn't range at the top, because even if mappings are not immediately visible, the flute-like arrangement of the pressure pads incites users to play it like a flute.
– On the *Musical Control* axis the Quarterstaff falls into the most differentiated category, since the gestural controls can clearly be applied at the timbral level.
– The *Feedback Modalities* axis indicates a high level of feedback given to the user: the feedback modes are visual, auditory, tactile, and kinaesthetic. It doesn't fulfil all categories equally well, but offers a good blend of those modes.
– On the *Degrees of Freedom* axis the instrument scores moderately high, because it offers a number of channels of interactions, but the number of them is deliberately limited.
– On the *Inter-actors* axis the Quarterstaff score the minimum, since it is conceived to be played by one person.
– For the *Distribution in Space* axis a medium value was selected, since the instrument does have a spatial interaction domain, scaled to the dimensions of the human body.
– Finally on the *Role of Sound* the instrument clearly falls into the artistic/expressive category.

In this analysis it seems that the Quarterstaff presents a similar top-heavy dimensionality as the Hands [15] or the Theremin.

An interesting alternative interpretation can be achieved by applying Magnusson's epistemic dimension space [12] (see Figure 5).

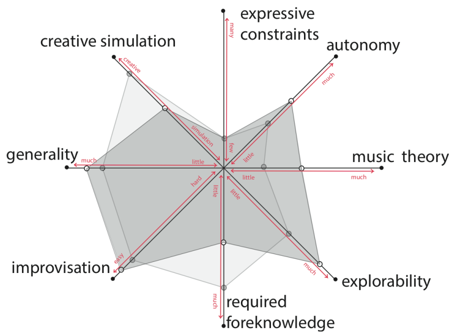

Figure 5: The Quarterstaff placed in the eight-dimensional epistemic space proposed by Magnusson. In comparison the values for 'the Hands' by Waisvisz are underlaid.

– The Quarterstaff scores a medium value on the *Expressive Constraints* axis since the design clearly enforces certain types of gestural and instrumental actions.
– The value scored on the *Autonomy* axis is related more to the software side of the instrument than the controller itself. In the concrete pieces performed with the Quarterstaff , autonomous processes are guided by minimal inputs from the gestural domain. This is an affordance and doesn't exclude other modes of operation.
– The only elements that gives the instrument a medium rating on the *Music Theory* axis is the evocation of a scale-like fingering given through the eight pads arranged in pattern reminding of a flute.
– The instrument rates high on the *Explorability* axis since the gestural affordances invite an exploration and do not enforce just one way of playing.
– For *Required Foreknowledge* the Quarterstaff aims at requiring little knowledge, by representing an actions space, gesturally but also musically.
– The instrument scores medium on the *Improvisation* axis, not because it doesn't lend itself to improvisation, but because the limited degrees of freedom constrain the space of expression and don't support immediate adaptations very well.
– On the *Generality* axis the Quarterstaff again doesn't score very high, due to its clearly scoped and determined

[7] To provide a better interpretation of the graphs, comparison with the ones in the cited publication is recommended.

design and modes of interaction. The software side of the instrument can be handled in a very general way, but the limited affordance of the interface limit the possible musical styles.

– In a sense the *Creative-Simulation* axis is the most difficult to determine. Although the design of the Quarterstaff is decidedly metaphor-based and tries to bring over physical skills from everyday objects, at the same time it presents an idiosyncratic and quite unique gestural domain that does not really imitate existing traditional instruments.

This analysis renders apparent a strong relation with the Hands [15] but also – in a transposed way –with the ixiQuarks [11].

The most useful comparisons that could be obtained through these analyses would be by comparing the Quartstaff with some of the staff-like bi-manual interfaces such as the 'T-stick' and the 'Karlax', but also the 'Lechero' and the 'Sormina'. Such an analysis would not only require access to all these devices but also exceed the scope of this article. The comparisons and exchange of experiences with other device makers and practitioners will have be the subject of a future publication.

7. CONCLUSION

The development of the Quarterstaff is based on a series of insights regarding performance with electronic sounds and new interfaces. By using design, fabrication and experimentation processes in an exploratory manner, experiences are collected that help to shed light on some of the core questions of the instrument-body relationship. This bond is what is necessary in order to perform music intuitively, making full use of our innate capacity for immediate, adaptively guided pre-reflective actions. In the context of NIME but even long before, this central issue of controllers and interfaces has become apparent. David Wessel puts it very succinctly when he says: "Clearly, the instrument should be easy to play. [...] The instrument should inspire the development of virtuosity. It should have a vast potential for musical expressiveness. [...] The instrument must be *composed*." [21] (my italics). The design and development of a gestural instrument occurs on the delicate boundary where these criteria collide and where ideally they enter into a state of balance. With the Quarterstaff project the curiosity about these instrumental and desire for building them has been quenched. Through that process and in the moments of performance a way forward for the development of the gestural digital instruments has become visible.

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