Developing A Physical Gesture Acquisition System for Guqin Performance

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ABSTRACT
Motion-based musical interfaces are ubiquitous. With the plethora of sensing solutions and the possibility of developing custom designs, it is important that the new musical interface has the capability to perform any number of tasks. This paper presents a physical gesture acquisition for Guqin performance. The framework is based on an iterative design process. It draws upon the knowledge in Guqin performance to develop a system to assess the interaction between a Guqin player and the computer. An application for extending Guqin performance will also be presented.

Author Keywords
NIME, iterative design process, Guqin, rapid prototyping, evaluation techniques, hand controller

ACM Classification
H.5.2 [Information Interfaces and Presentation] User Interfaces–Input devices and strategies, H.5.5 [Information Interfaces and Presentation] Sound and Music Computing–Methodologies and techniques

1. INTRODUCTION
The ongoing development of technology has impacted almost every aspect of the musical arts. The confluence of sensor technology and music since the late twentieth century have expanded and pushed the boundaries of performance, perspective, aesthetic, and composition of traditional music. This includes augmenting traditional instruments with sensors, building new controllers, and developing wearable sensor systems.

Prior research has addressed the design principles and guidelines to developing NIMEs. Cook observed that creating novel musical controllers is an artistic process rather than a scientific one, and that the device created is driven by the initial design decisions and techniques [3]. Fels presented a scientific approach that focused on the musician - suggesting that a musical interface is successful when the relationship of the mapping between control and sound is transparent to the player [4]. In [13], Paine argued that musical interfaces need to communicate intent, and the relationship between performance gestures and musical outcomes should be clear to the audience.

Vallis et al. presented the approach of iterative controller development in which researchers create new interfaces, based on existing interfaces, that are customized to the users' needs [18]. In these (and other) research projects, the artistic, design, and human factors are important; however, the technical aspect has yet to be addressed, even though it is integral, since most interfaces work in conjunction with a computer.

Motivated by the aforementioned design principles and the shift in our field towards iterative design, this paper presents the development of a physical gesture acquisition system for Guqin performance based on the theoretical framework of iterative-based development for NIMEs. Section 2 presents an overview of the development process of the physical gesture acquisition system for Guqin performance. Section 3 presents the acquisition system and explains the logistics of the approach. Application of the acquisition system for interaction between a Guqin player and a mechatronic musical instrument will also be discussed. This paper concludes with a brief overview and future works that extend the current research and practice.

2. ITERATIVE-BASED FRAMEWORK
The acquisition system was first implemented through rapid prototyping. This resulted in *Kontrol*, a hand controller for performing artists that uses accelerometers and machine learning to recognize hand gestures [2]. Unlike other hand controllers, *Kontrol* exposes the fingers thereby enabling the player to directly interact with the instrument. The development of *Kontrol* followed an iterative design process – we designed the controller, prototyped the hardware and software, and then evaluated through its application in various performance contexts. Eventually, changes were made to improve the design, resulting in newer versions. Figure 1 shows the version history.

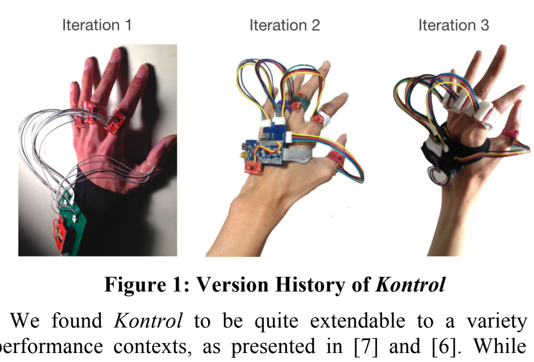

Figure 1: Version History of *Kontrol*

We found *Kontrol* to be quite extendable to a variety of performance contexts, as presented in [7] and [6]. While its application in different musical performances helped improve the design of the controller, the parameterization of the acquired data to audio parameters through arbitrary mapping schemes is not sufficient as a technical evaluation method. Drawing upon the engineering design processes, the development process of the physical gesture acquisition system begins with defining the requirements of the acquisition system. Thereafter, the prototype is designed and built to the requirements. Then, the device is evaluated through two tests: 1) a comparison of the prototype's measurement and the required measurements, and 2) the parameterization of acquired data in a variety of performance context.

3. Physical Gesture Acquisition System for Guqin Performance

3.1 History, Motivation and Aim

The Guqin is a Chinese fretless plucked seven-stringed instrument with a history of about 3000 years. It is also considered to be the "Father" of Chinese instruments, and was proclaimed as one of the *Masterpieces of the Oral and Intangible Heritage of Humanity* by United Nations Educational, Scientific and Cultural Organization in 2003 [17]. The instrument's modulation techniques known as *Zou Shou Yin* are known to define the distinct characteristics of the instrument: the fluid modulation of pitch and the dynamics and timbre in the tones created by the combination of the left and right hand finger techniques. While the right hand plucks the string, most of the stylistic information of the tones is produced by the left hand gestures, which are often complex techniques that are unique to each instrumentalist. There are four major categories of left hand finger techniques: *yin*, *nao*, *chuo* and *zhu*.

The motivation of this research is to gather physical data from master Guqin performers to digitally preserve the physical attributes of performance technique, since these techniques are often passed down viva voce and there is, as of yet, no other standard to preserve this important information.

3.2 Specifying the Requirements

In order to measure the nuances in physical gestures, the following components of the acquisition system need to be defined:

1. What do you need to measure?
2. What is the required range of measurement?
3. What is the required resolution of measurement?

Through examining *Taiyin Da Quan Ji* (a collection of all printed Guqin handbooks since 1425 CE) [20], and academic reports by Guqin researchers [5,19], hand postures are executed using the metacarpophalangeal (MCP) joint of the thumb, pointer finger, middle finger, and ring finger, and of the wrist.

To measure the joint angles of the left wrist and MCP, the human's typical range of motion (ROM) is used as reference [16]. Intrinsically, the joint angles of the wrist can also be described in terms of Euler angles (Figure 2).

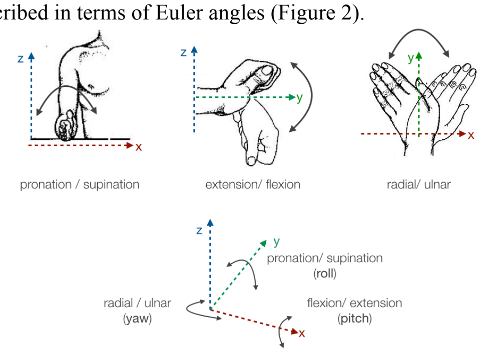

Figure 2: Wrist motions described in Euler Angles

As reported in [8], the shortest time interval for Guqin's portamento technique is 20 milliseconds. Thus, a sampling rate of at least 100 Hz is required. In addition to the abovementioned technical requirements, the acquisition system needs to be:

- Minimally obstructive - Figure 3 shows areas of fingers of the left hand that should not be obstructed.
- Fieldwork-ready - Not confined to the instrumented environment, portable, and non-cumbersome to setup.
- Performable - can be used in live performance as a musical controller.

Figure 3: Areas of fingers used to perform flageolet tones and stopped sounds

For the acquisition system to be performable, the latency of the computer receiving the physical gesture data should be less than or equal to 30 milliseconds (latency tolerance in music performance) [9]. Table 1 summarizes the requirements of the acquisition system.

Table 1: Summary of Measurement Requirements

	Min:	Max:	Range:	Resolution
Flexion/ Hyperextension (fingers)	45 ° (HE)	90 ° (F)	≈ 135 °	1.0 °
Flexion/ Extension (wrist)	70 ° (E)	75 ° (F)	≈ 145 °	1.0 °
Pronation/ Supination (wrist)	70 ° (P)	85 ° (S)	≈ 155 °	1.0 °
Radial/ Ulnar (wrist)	30 ° (R)	20 ° (U)	≈ 50 °	1.0 °
Sample Rate	100 Hz	-	-	
Latency	-	30 ms	-	

3.3 Designing to Requirements

As reported in previous research [14], audio analysis of Guqin music is prone to interference due to the characteristics of its music:

i. Open string tones preceding the current tone have yet to decay fully.
ii. The sliding of fingers on the strings generates audible friction noise. This is especially prominent with Guqin that uses silk strings.
iii. Inharmonic overtone structure and the weak fundamental pitch of certain tones cause octave and fifth errors in pitch detection.

Although audio and acoustical analyses provide pitch, timbre, and temporal information that are vital, they do not explicitly describe the physical details of the performer's gestures that produce the tones.

Due to the playing schema of the Guqin, an optical approach will be subjected to occlusion. Moreover, it requires the environment to adhere to strict lighting conditions, which may be uncontrollable during fieldwork. Additionally, the Guqin is approximately 125 cm $\pm$ 5 cm in length with an active string length of 120 cm $\pm$ 5 cm. An optical device with a regular lens (F3.2) would need to be placed 145 cm above the instrument. High-resolution motion capture systems are not portable and constrain the data acquisition to the instrumented environment.

As the Guqin is regarded as prized object, and its status as a representation of nature and spirituality discourages the modification of the physical entity, the use of different materials to construct an alternative controller may affect the natural method of performance – specifically the execution of sliding tones. Furthermore, it is cumbersome to transport the instrument (or an alternative, equivalent controller) for fieldwork due to its dimensions. Thus, a wearable sensor approach is employed to extract the physical gesture data of Guqin performer.

3.4 Implementation

Iterating off *Kontrol* and *ArduIMU Glove* (as presented in [10,11]), *Flexpoint*[1]'s bend sensors were chosen to measure the flexion and hyperextension of fingers' MCP. A motion-processing unit, MPU-9150 (3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer) by Invensense[2], measures the tilt and rotation of the wrist. Its on-board DMP processor performs the sensor fusion to generate selectable outputs, such as quaternion data and acceleration data with gravity removed. It also adjusts for the world frame of reference, whereby yaw is relative to the orientation at initialization. This reduces the processing load of the microcontroller. As reported in a study utilizing MPU-9150 to measure limb movements, the motion-processing unit measures tilt and rotation with a mean error of less than 0.9 degrees in both static and dynamic states [1].

The bend sensors are connected as a simple voltage divider to the 10-bit ADC inputs of the microcontroller (3.3 V, 8 Mhz). The value of the second resistor is optimized using [15]. Figure 4 shows that bend sensors measure within the required resolution (mean ≈ 0.74°, sd = $\pm$ 0.16°). MCP angles are measured using a finger goniometer with a range of 30° hyperextension to 120° flexion, marked in 1° increment.

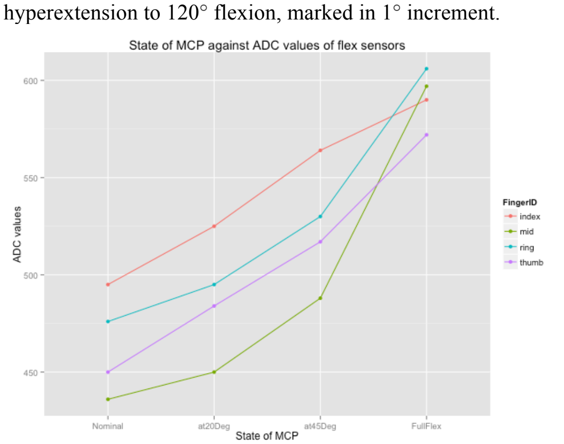

Figure 4: State of MCP versus ADC values of bend sensors

1 http://www.flexpoint.com
2 http://www.invensense.com

The microcontroller samples and sends data wirelessly to an external computer at 100 Hz through a serial protocol using Xbee Series 1. Xbee Series 1 was chosen over Bluetooth for its lower power consumption and straightforward integration. Figure 5 shows an example of the acquired physical gesture data during the *nao* gesture.

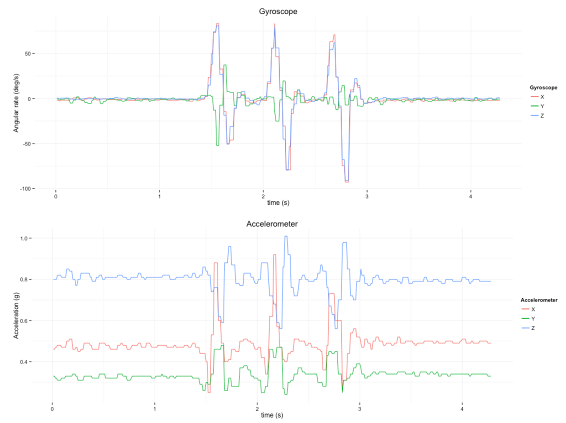

Figure 5: Example of sensor data output of *nao* gesture from accelerometer and gyroscope of MPU-9150

The latency of the system is measured by the time interval between the stimulation from the computer to request for sensor data and complete receipt of sensor data from the musical interface (response). The mean latency is 4.62 milliseconds with a standard deviation of 2.47 milliseconds (100 iterations of stimulation and response).

Figure **6** shows the latest iteration of the physical gesture acquisition system. The top-end of each bend sensor is aligned with the finger's proximal interphalangeal joint, and the MPU-9150 is centered horizontally and vertically on the back of the palm.

Figure 6**: Physical gesture acquisition system for Guqin performance**

3.5 Evaluation

Based on the comparison as shown in Table 2, the new physical gesture acquisition system met the measurement requirements as specified.

In addition to the evaluation against the requirements, the physical gesture acquisition system was used in *Knowing One's Sound*, a performance at the 2015 International Conference on NIME in Baton Rouge, Louisiana. In the performance, various chosen Guqin gestures were used to control parameters of *Swivel 2*, a parametrically rich mechatronic chordophone [12].

Physical gesture data was used to recognize different traditional Guqin gestures using the scheme presented in [6], and the recognition output is used for score following. The score follower then instructs *Ableton Live*[3] to send MIDI sequences to *Swivel 2*, while the derived data of the system (such as finger flexion, wrist flexion and pronation) modulates the MIDI sequences. As demonstrated through the performance, the system performs consistent desired gesture tracking.

Table 2: Comparison of Acquisition System's Measurement against Measurement Requirements

	Resolution Required	System's Resolution
MCP Flexion/ Extension	1.0 °	0.33 °
Wrist Pronation/ Supination	1.0 °	Mean of error < 0.9 °
Wrist Radial/ Ulnar Deviation	1.0 °	
Sample Rate	100 Hz	100 Hz
Latency	30 ms	4.62 ms (± 2.47)

4. CONCLUSION

In summary, this paper presented the development of a physical gesture acquisition system for Guqin performance. Through rapid prototyping, the first version of the system was developed. Subsequent iterations followed, with the refinements of its design informed by evaluating the system through a variety of performance contexts. However, after several iterations, the performance context evaluation method was found to be insufficient in providing meaningful evaluation results.

The development of the latest iteration of the physical gesture acquisition system for Guqin performance utilizes an additional process of defining the measurement requirements of the acquisition system. As discussed, measurement requirements are based upon the knowledge of the instrument's theory and practice (rather than by trial-and-error) and just noticeable differences in musical performance. A more robust evaluation that provides meaningful results is achieved when the evaluation method of parameterizing acquired data in different performance contexts is coupled with comparison of the measurements output of the prototype and the measurement requirements.

Future research may be done in the analysis of Guqin performance techniques to compare and model the different Guqin playing styles.

5. REFERENCES

[1] Buonocunto, P. and Marinoni, M. Tracking limbs motion using a wireless network of inertial measurement units. *Industrial Embedded Systems (SIES), 2014 9th IEEE International Symposium on*, IEEE (2014), 66–76.

[2] Christopher, K., He, J., Kapur, R., and Kapur, A. Kontrol: Hand Gesture Recognition for Music and Dance Interaction. *Proceedings of the 2013 International Conference on New Interfaces for Musical Expression*, 2013, 267–270.

[3] Cook, P. Principles for designing computer music controllers. *Proceedings of the 2001 conference on New interfaces for musical expression*, National University of Singapore, 2001, 1–4.

[4] Fels, S. Designing for intimacy: Creating new interfaces for musical expression. *Proceedings of the IEEE 92*, 4 (2004), 672–685.

[5] Guan, P., Wang, M., and Wang, D. *A research on the ancient finger (playing) techniques (《古指法考》).* Research Institute of Chinese Music, Central Conservatory of Music, Bejing, 1963.

[6] He, J. Beyond the Paradigm of Sound: Aesthetics and Methodologies in Contemporary Sonic Art Practices. 2013.

[7] He, J. Sonic Evocations. *Proceedings of the 2014 International Conference on Computation, Communication, Aesthetics and X*, 2014.

[8] Henbing, L. and Leman, M. A Gesture-based Typology of Sliding-tones in Guqin Music. *Journal of New Music Research 36*, 2 (2007), 61–82.

[9] Mäki-Patola, T. and Hämäläinen, P. Latency tolerance for gesture controlled continuous sound instrument without tactile feedback. *Proceedings International Computer Music Conference (ICMC)*, 2004, 1–5.

[10] Mitchell, T.J. Soundgrasp: A gestural interface for the performance of live music. *Proceedings of the 2011 Internationnal Conference on New Interfaces for Musical Expression*, 2011.

[11] Mitchell, T.J., Madgwick, S., and Heap, I. Musical interaction with hand posture and orientation: A toolbox of gestural control mechanisms. *Proceedings of the 2012 International Conference on New Interfaces for Musical Expression*, 2012.

[12] Murphy, J., McVay, J., Mathews, P., Carnegie, D.A., and Kapur, A. Expressive Robotic Guitars: Developments in Musical Robotics for Chordophones. *Computer Music Journal*, (2015).

[13] Paine, G. Towards unified design guidelines for new interfaces for musical expression. *Organised Sound 14*, 02 (2009), 142–155.

[14] Penttinen, H., Pakarinen, J., Välimäki, V., Laurson, M., Li, H., and Leman, M. Model-based sound synthesis of the guqin. *The Journal of the Acoustical Society of America 120*, 6 (2006), 4052–4063.

[15] Schmeder, A. Optimizing the voltage divider pullup / pulldown circuit for resistive analog sensing | CNMAT. *Optimizing the voltage divider pullup / pulldown circuit for resistive analog sensing | CNMAT*, 2008. http://cnmat.berkeley.edu/user/andy_schmeder/blog/2008/08/08/optimizing_voltage_divider_circuit_resistive_analog_sensing.

[16] Soucie, J.M., Wang, C., Forsyth, A., et al. Range of motion measurements: reference values and a database for comparison studies. *Haemophilia 17*, 3 (2011), 500–507.

[17] United Nations Educational, Scientific and Cultural Organization. The Art of Guqin Music. 2004. http://www.unesco.org/culture/intangible-heritage/masterpiece.php?id=65&lg=en.

[18] Vallis, O., Hochenbaum, J., and Kapur, A. A shift towards iterative and open-source design for musical interfaces. *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2010, 1–6.

[19] Wu, W. *Wu Jinglue's qin music in its context.* Wesleyan University, 1990.

[20] Zha, F., ed. *Tai Yin Da Quan Ji (太音大全集).* ZhongHua Book Company (中华书局), Shanghai, 2010.

[3] http://www.ableton.com