Kritaanjli: A Robotic Harmonium for Performance, Pedogogy and Research

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ABSTRACT

In this paper, we introduce Kritaanjli, a robotic harmonium. Details concerning the design, construction, and use of Kritaanjli are discussed. After an examination of related work, quantitative research concerning the hardware chosen in the construction of the instrument is shown, as is a thorough exposition of the design process and use of CAD/CAM techniques in the design lifecycle of the instrument. Additionally, avenues for future work and compositional practices are focused upon, with particular emphasis placed on human/robot interaction, pedagogical techniques afforded by the robotic instrument, and compositional avenues made accessible through the use of Kritaanjli.

Keywords

Musical Robotics, pedagogy, North Indian Classical Music, augmented instruments

1. INTRODUCTION

To date, many musical robots detailed within the NIME community have relied upon percussion instruments as sound sources. The authors' previous works [9] as well as those of Gil Weinberg and associates [17] and much of Eric Singer's work with his LEMUR collective [13] have explored musical expression as derived from percussive sources. In an effort to introduce musical robotic systems in differing instrument families to the community, we introduce Kritaanjali, a robotic harmonium.

Prior to the introduction of Kritaanjli, the first two authors' works have consisted only of instruments in which sound is derived from solenoid-powered drum beaters and percussion mallets striking surfaces such as drums and tuned bars [8]. With the authors' increasing focus upon creating a full robotic ensemble in the Machine Orchestra [9], the need for robots with wider timbral diversity has become evident. To address this need, Kritaanjli was developed.

Kritaanjli is a robotic harmonium with 44 solenoid actuators and a variable-speed bellows pumping mechanism. Each key of the harmonium has an accompanying solenoid: this parallel actuator configuration affords extended technique compositional practices wherein large tone clusters can be created. This ability to create tone clusters and dense timbres introduces elements of sonic diversity into the otherwise percussion-dominated Machine Orchestra.

A harmonium was chosen as the first non-percussive instrument in the authors' robotic ensemble for three reasons. Primarily, the harmonium is a relatively simple keyboard instrument which avoids many engineering problems associated with more complex keyboard instruments. While complex instruments such as the piano allow for individual dynamic control on each note, the harmonium keys simply serve as momentary switches, permitting air to flow past reeds at a rate governed by the amount of air forced by the bellows. Secondly, the harmonium's established role as a North Indian classical instrument fits within the conceptual and aesthetic framework of the first author's previous works [7]. Further, the harmonium is a central instrument in North Indian classical music pedagogy: the authors are interested in exploring musical robotics as a means by which such pedagogy can be enhanced. Finally, the design of the harmonium allows for non-destructive augmentation: an existing harmonium can be converted to a Kritaanjli-style robot with no permanent modifications. This final feature allows for existing instruments to be temporarily used as musical robots and then reconverted to traditional human-operated harmoniums.

This paper will begin with a discussion of related work in non-percussive musical robotics. Section 3 provides a technical overview of Kritaanjali, complete with quantitative studies undertaken in the design phase of the project as well as a thorough discussion of the design lifecycle of the instrument. The paper concludes with an exposition of a series of current and future applications of Kritaanjli.

Figure 1: Kritanjali's actuator array

NIME'12, May 21 – 23, 2012, University of Michigan, Ann Arbor.

2. RELATED WORK

The design of Kritaanjli owes much to the fully mechanical player pianos and organs of the Industrial Revolution. Such organs typically combined keyboard actuating mechanisms with mechanically-driven bellows pumps [4]. The 1970's, though, saw modern musical robotics begin in earnest with the works of Godfried-Willem Raes of the Logos Foundation [10] and sound artist Trimpin [3]. Both of these artists have done much over the past four decades to advance both the artistic and technical aspects of the field of musical robotics: Trimpin's prepared piano assembly *Contraption IPP* served as a major inspiration in the design and execution of Kritaanjli.

The last twenty years have seen much new work pertaining to musical robotics, with the team of researchers at Waseda University in Japan remaining consistently at the forefront of research [12]. Eric Singer's robotic collective LEMUR, founded in 2000, has produced technologically advanced robots and, through Singer's work with guitarist Pat Metheny's Orchestrion project in 2010, brought a wide degree of public exposure to the burgeoning field of musical robotics. Singer's use of closed-loop control in his GuitarBot [14] served as an inspiration for the bellows mechanism on Kritaanjli. A main focus of the Kritaanjli project is that of human-robot interaction (see Section 4.3). Gil Weinberg's work has in recent years broken much new ground in the study of musical robotic interaction with human performers. In addition to his work, the first author's prior research contributed to the use of Kritaanjli as a tool for pedagogy and real-time improvisation with human performers. In the last five years, many new examples of continuous, non-percussive musical robots have appeared, including [2] and [12]. It is the authors' belief that the future of musical robotics promises to play host to works with ever-increasing sonic complexity and enhanced human-robot interaction.

3. TECHNICAL DESIGN

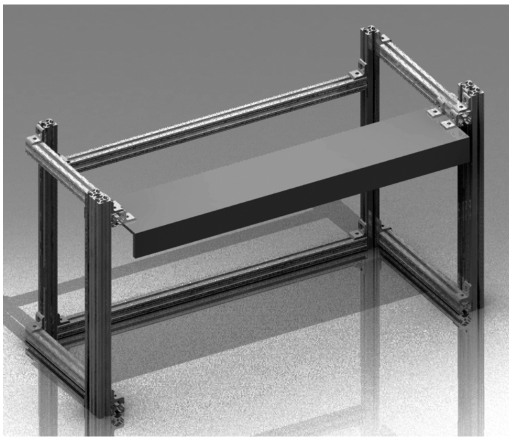

Figure 2: A visualization of a CAD drawing of Kritanjali's frame and solenoid mount.

The harmoniums used in Kritaanjli are small hand-pumped reed organs. Such instruments were introduced to India by Christian missionaries in the 19th Century and were subsequently adopted into Indian classical, devotional, and folk music [1]. Harmoniums function by forcing air past reeds opened by the depression of keys. The amount of air forced past the reeds governs the loudness of the instrument and is varied by changing pumping rate. Harmoniums continue to be used as an accompanying instrument and a pedagogical tool. The following subsections will focus on the augmentation of such a harmonium to allow for mechatronic control of the instrument.

3.1 Design Overview

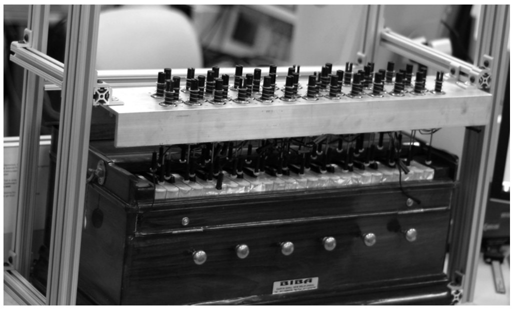

Figure 3: Kritanjali under construction.

Kritaanjli consists of an aluminum framework which surrounds a harmonium. Attached to the framework assembly are three major subassemblies: the electronics enclosure, the bellows-pumping mechanism, and the keyboard actuation mechanism. T-bracket aluminum extrusions similar to those in many of the first authors' previous works were chosen as the materials for Kritaanjli's framework due to the flexible modularity which they afford: mounting subassemblies to the aluminum extrusions proved simple and efficient. The electronics enclosure houses the microcontroller and daughterboards (see Section 3.3) and is mounted directly on the frame to minimize distance of cable runs.

To pump the harmonium's bellows, a DC electric motor is connected by means of a crank mechanism first to a crankshaft and then with a clamp directly to the rear of the bellows. The crank travels about the motor's hub on a wheel with a diameter equal to the harmonium bellow displacement. To vary the harmonium's output volume, the motor speed can be increased; additionally, harmonium motor speed must be increased to maintain a constant volume as more keys are depressed. Key presses are achieved through the use of linear DC solenoids arranged in an array above the harmonium's keyboard. Each key has an accompanying dedicated solenoid. The solenoids are mounted on an aluminum bracket and are connected individually to a MOSFET driver board contained within the electronics enclosure.

3.2 CAD/CAM

Kritaanjli was created using computer aided drafting (CAD) technology: prior to any physical construction, the harmonium and its mechatronic additions were drafted in the solid modeling tool SolidWorks. The use of CAD in the design cycle of Kritaanjli allowed for rapid iterative design: design problems and conflicts could be addressed prior to physical fabrication and modifications to the existing design could be quickly tested in the CAD software with no downtime due to assembly and disassembly of the existing system. Figure 2 shows the CAD model of Kritanjali.

CAD techniques were coupled with computer aided manufacturing (CAM) technologies to permit rapid and precise prototyping and fabrication of Kritaanjali's components. Each harmonium is a hand-built instrument with loose mechanical tolerances: to create a linear array of holes, measurements were taken to ensure that the solenoids were to be correctly positioned above the non-equidistantly spaced keys. In order to replicate the measurements in the final aluminum solenoid bracket, holes were cut using a high-precision CNC milling machine. Additionally, mechanical components of Kritaanjli such as the bellows motor bracket, the crankshaft, and the bellows crankshaft clamp were produced with the aid of a laser cutter. The user of a laser cutter allowed for the production of relatively high precision parts with very little lead time.

The CAD/CAM workflow has in recent years gained much popularity in the open source hardware community. Works such as the Fab Lab [5] and the RepRap project [6] point toward a future of highly integrated solutions to design and manufacture of custom parts. Such developments have strong implications for NIME research: we found that the workflow proved highly efficient and will continue to make use of the CAD/CAM paradigm in future works.

3.3 Actuation

Solenoids were chosen as actuators to press the harmonium's keys. 24V DC solenoids were mounted above the keys. Prior to subsequent modifications, the solenoids were pull-type, retracting their plunger arms into the barrel. All were subsequently modified to become push-style solenoids, allowing the solenoids to depress the harmonium's keys. Two versions of Kritaanjli's keyboard assembly were produced: the first used solenoids which rested 2cm above the keys and were returned to their origin with the aid of springs attached to the solenoid's shaft.

A small amount of latency between signal transmission and key depression was noticed. Further tests showed that with increasing distance from the struck surface and decreasing voltage applied to the solenoid, latency increased. To remedy this, the natural spring-return of the harmonium's keys were utilized on the second iteration of Kritaanjli's keyboard: the solenoids were mounted such that they pressed against the keys and were returned to their original displacement with the spring-return of the key itself. This arrangement reduced latency between instructing the solenoid to actuate and the actual actuation event.

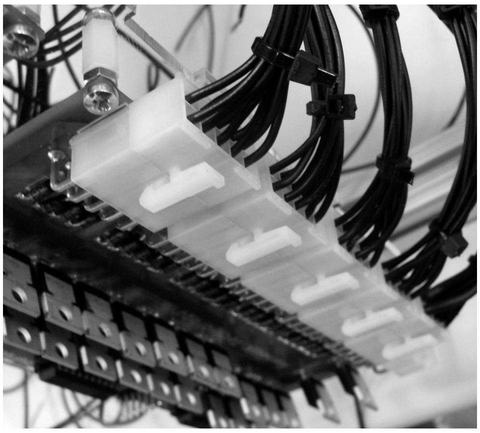

Figure 4: Kritanjali's MOSFET-based driver board.

While 24V Ledex-brand DC solenoids were chosen to depress the harmonium's keys, the minimum voltage possible to press each key was applied to the solenoids. The use of minimum voltages was chosen in order to avoid actuation noise and to prevent unnecessary force from being applied to the harmonium's keys. Through experimentation, the maximum voltage necessary to depress the stiffest of the harmonium keys was 11V with a variability of 1V volts: 12V were therefore applied to all key solenoids. The use of 12V instead of 24V will greatly reduce wear and tear on the harmonium keys as well as reduce audible solenoid actuation noises.

A small Pololu-brand DC motor was used to pump the

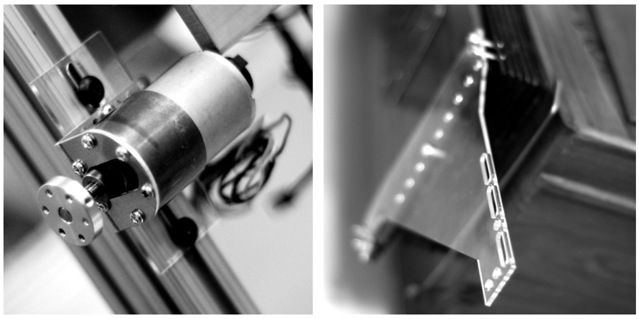

Figure 5: Laser-cut motor mount and bellows hinge.

harmonium: attached to the bellows with a custom-fabricated crankshaft mechanism, the DC motor utilizes a hall-effect encoder to provide rotational feedback. The use of an externally-mounted non-destructive pump mechanism allows for augmentation of any pump-equipped harmonium. To create the non-destructive bellows mount, the harmonium was measured and a suitably-sized bracket was created. The bracket was clamped to the rear of the bellows and attached to the motor: as the motor turned, the bellows reciprocate. The motor's speed is controlled with a power MOSFET driven with a PWM signal from an AVR microcontroller. Future work will focus on attempts to reduce the noise produced both by the solenoids and DC motor.

4. APPLICATIONS AND FUTURE WORK

4.1 Performer/Robot Interaction

With Kritaanjli, human/robot interaction is extensively explored. This work, inspired in part by Gil Weinberg's research [16, 17], focuses on duo-style improvisation between a human player and Kritaanjli. A key element of the human/robot improvisation lies in Kritaanjli's ability to mimic human performance techniques. To engage in this improvisation, two primary elements are needed: an augmented harmonium to allow for feature extraction from human performers and a means by which the extracted performance information can be reflected in Kritaanjli's performance.

An initial avenue of research currently being conducted is that of emulation of human player harmonium pumping: this is accomplished through pump displacement information gathered with the use of a linear displacement sensor and converted to setpoint information in a PID controller connected to Kritaanjli's encoder-equipped bellows motor. Future work will build upon this research, growing to include other aspects of harmonium playing such as keyboard technique.

4.2 Raag Database

As mentioned in [1], harmoniums are often used as a pedagogical instrument to aid in the teaching of Indian classical music. We recognize the potential of Kritaanjli to serve as an automatic accompaniment instrument to augment traditional pedagogy techniques. To serve in this role, we have begun the creation of a raga database for Kritaanjli which will allow the instrument to be rapidly reconfigured to play in different ragas. Through the use of the Kritaanjli Raga Database, ragas, which serve as the underpinning melodic modes in Indian classical music, can be switched, modified, and improvised upon.

The database has been implemented in the ChucK programming language [15]. A wide variety of ragas are stored in the database: each raga can be improvised upon, allowing musicians to gain an understanding of the selected raga's characteristic in a real-time manner. The Kritaanjli Raga Database will play an important role in future work with Kritaanjli and human/robot interaction: the database will be augmented to allow for real-time raga recognition and subsequent improvisation.

4.3 Performance: Interfacing with Musicians

As mentioned in Section 1, Kritaanjli fills a new role in the KarmetiK Machine Orchestra: that of melodic and harmonic sustained sound. Prior melodic and harmonic instruments have consisted of struck tuned bars, as on KarmetiK's Glockenbot and Tammy robots [9]: the presence of an instrument with sustained tonality will open new compositional avenues. Kritaanjali will appear in future Machine Orchestra performances: to further extend the capabilities of the instrument, we have explored connecting Kritaanjli with a number of custom-built musical interfaces such as that described in [11]. The gestural expressivity afforded by such interfaces serves as a means by which Kritaanjali's capabilities for extended technique performance scenarios may be explored.

5. CONCLUSIONS

With the creation of Kritaanjli, we have extended the array of robots used in the KarmetiK Machine Orchestra from those capable of percussive sounds to those capable of harmonic and melodic sounds of a sustained nature. Kritaanjli serves as a non-destructive means by which an existing harmonium can be modified to behave as a musical robotic agent for performance and pedagogy. The harmonium was chosen for its relative simplicity: unlike pianos and other keyboard instruments with individual dynamic range on each note, the harmonium allows for a simplified on/off control over each note with dynamics controlled via bellows pumping action. Further, Kritaanjli differs from instruments wherein notes are selected serially: the parallel approach in which each key possesses an accompanying solenoid affords composers the ability to craft large chordal structures. Kritaanjli opens the door to novel future work, including research focused on performer feature extraction, new pedagogical techniques, and explorations in robotic ensemble performance.

6. REFERENCES

[1] K. Brockschmidt. *The Harmonium Handbook*. Crystal Clarity Publishers, 2003.

[2] R. Dannenberg, H. Brown, and R. Lupish. Mcblare: A robotic bagpipe player. In J. Solis and K. Ng, editors, *Musical Robots and Interactive Multimodal Systems*, volume 74 of *Springer Tracts in Advanced Robotics*, pages 165–178. Springer Berlin / Heidelberg, 2011.

[3] A. Focke. *Trimpin: Contraptions for Art and Sound*. Marquand Books, Seattle, Washington, 1st edition, 2011.

[4] C. Fowler. The museum of music: A history of mechanical instruments. *Music Educators Journal*, page 45, October 1967.

[5] N. Gershenfeld. *Fab: The Coming Revolution on Your Desktop–from Personal Computers to Personal Fabrication*. Basic Books, 2007.

[6] R. Jones, P. Haufe, E. Sells, P. Iravani, V. Olliver, C. Palmer, and A. Bowyer. Reprap : the replicating rapid prototyper. *Robotica*, 29(01):177–191, January 2011.

[7] A. Kapur. *Digitizing North Indian Music: Preservation and Extension using Multimodal SensorSystems, Machine Learning and Robotics*. VDM Verlag, 2008.

[8] A. Kapur and M. Darling. A pedagogical paradigm for musical robotics. In *Proceedings of the 2010 Conference on New Interfaces for Musical Expression*, Sydney, Australia, 2010.

[9] A. Kapur, M. Darling, D. Diakopoulos, J. Murphy, J. Hochenbaum, O. Vallis, and C. Bahn. The machine orchestra: An ensemble of human laptop performers and robotic musical instruments. *Computer Music Journal*, 25(4):49.

[10] T. R. Laura Maes, Godfried-Willem Raes. The man and machine robot orchestra at logos. *Computer Music Journal*, 35(4):28–48, 2011.

[11] J. Murphy, A. Kapur, and C. Burgin. The helio: A study of membrane potentiometers and long force sensing resistors for musical interfaces. In *Proceedings of International Conference on New Instruments for Music Expression*, Sydney, Australia, 2010.

[12] K. Shibuya, S. Matsuda, and A. Takahara. Toward developing a violin playing robot - bowing by anthropomorphic robot arm and sound analysis. In *Proceedings of RO-MAN 2007*, Jeju Island, Korea, 2007.

[13] E. Singer, J. Feddersen, C. Redmon, and B. Bowen. Lemur's musical robots. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, Hamamatsu, Japan, 2004.

[14] E. Singer, J. Fedderson, and D. Bianciardi. Lemur guitarbot: Midi robotic string instrument. In *Proceedings of the 2003 International Conference on New Interfaces for Musical Expression*, Montreal, Canada, 2003.

[15] G. Wang. *The ChucK Audio Programming Language: An Strongly-timed and On-the-fly Environ/mentality*. PhD thesis, Princeton University, 2008.

[16] G. Weinberg, B. Blosser, and T. Mallikarjuna. The creation of a multi-human, multi-robot interactive jam session. In *Proceedings of International Conference on New Instruments for Music Expression*, Pittsburgh, PA, 2009.

[17] G. Weinberg and S. Driscoll. Toward robotic musicianship. *Computer Music Journal*, 30(4):28.