Gamelan Elektrika: An Electronic Balinese Gamelan

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ABSTRACT

This paper describes the motivation and construction of Gamelan Elektrika, a new electronic gamelan modeled after a Balinese Gong Kebyar. The first of its kind, Elektrika consists of seven instruments acting as MIDI controllers accompanied by traditional percussion and played by 11 or more performers following Balinese performance practice. Three main percussive instrument designs were executed using a combination of force sensitive resistors, piezos, and capacitive sensing. While the instrument interfaces are designed to play interchangeably with the original, the sound and travel possiblilities they enable are tremendous. MIDI enables a massive new sound palette with new scales beyond the quirky traditional tuning and non-traditional sounds. It also allows simplified transcription for an aurally taught tradition. Significantly, it reduces the transportation challenges of a previously large and heavy ensemble, creating opportunities for wider audiences to experience Gong Kebyar's enchanting sound. True to the spirit of oneness in Balinese music, as one of the first large all-MIDI ensembles, Elek Trika challenges performers to trust silent instruments and develop an understanding of highly intricate and interlocking music not through the sound of the individual, but through the sound of the whole.

Keywords

bali, gamelan, musical instrument design, MIDI ensemble

1. INTRODUCTION

Gamelan has been performed for hundreds of years in Indonesia. The term gamelan is a general reference to a musical ensemble which can take many forms. One of the most famous is the metalophone instruments of the Balinese Gong Kebyar. It is renowned for the shimmer, intricate elaborate melodies and the tight interlock and togetherness of the playing ensemble. Uniquely in Balinese gamelan, the instruments come in pairs, where each instrument is slightly out of tune with the other half of the pair resulting in acoustical beats. A characteristic of Balinese composition is the interlocking of parts; a single line is regularly split between two instruments and two players resulting in quick, intricate rhythms. Additionally, gamelan is based on different versions of pentatonic tuning with each gamelan set having its own related but distinct tuning. No two gamelans are the same [3].

Figure 1: Galak Tika's *gangsa* and *reongs* including instruments from the Beta gamelan at the rear.

Balinese Gamelan is immensely popular in Bali, which hosts large national ensemble competitions. Study of the instruments first spread to the US in 1958 [8]. Balinese works are through composed and taught aurally. The Massachusetts Institute of Technology hosts Gamelan Galak Tika (GGT), founded in 1993 under the direction of Evan Ziporyn. With regular performances around the East Coast including Carnegie Hall, Lincoln Center, Brooklyn Academy of Music, and the Bang on A Can Marathons, GGT is a musical innovator focusing on new works by both Balinese and American composers. GGT owns two sets of instruments. The first set was somewhat hard to blend to Western tonalities so a second set, the Beta gamelan, was commissioned from Bali with a different tuning more suitable for projects with Western instruments. Tunning is not just a problem for GGT. Dewa Ketut Alit, one of the foremost composers in Bali, has also turned to working with multiple gamelans for a larger pitch range within a single composition.

Tuning is not the only limitation gamelan faces. The en-

*The company Harmonix was not involved in this project.

semble itself is large and very heavy. The instruments are metalaphones, including large gongs, brass or bronze pots and *gangsa* with 1/2 inch thick brass/bronze keys and solid heavy frames. Transporting the gamelan to a performance is a significant task on its own. With the mundane issues of tuning and transport continually complicating commissions and performance, through the generous support of Alex Rigopulos and Sachi Sato, GGT's Gamelan Elektrika was born: a more compact electronic version of the original instruments. Since the new instruments provide MIDI, Elektrika simultaneously gave access to new sounds and new tunings with as close to the original interface as possible. Another benefit is that MIDI is easily transcribable, proving a valuable tool to any Balinese ethnomusicologist documenting the aural tradition.

Gamelan Elektrika is not just about the instruments, but as gamelan should be, it is about the ensemble. Elektrika involves at least 11 performers playing often highly detailed interlocking parts on silent MIDI instruments. Any serious musician knows how important audible feedback from their instrument is, yet Elektrika is an essentially silent orchestra. MIDI signals are routed to a single brain that has complete control over the player's sound. We believe this is the first significant large ensemble of this form.

2. THE GAMELAN INSTRUMENTS

Gamelan Elektrika is a subset of a *gong kebyar* ensemble. *Gong kebyar* is presently the most popular form of gamelan within Bali and is usually the focus for the most ambitious compositions.

A full *Gong Kebyar* can have 24 or more instruments tuned to a pentatonic scale termed *pelog*. There are four instruments that are almost exclusively percussion: the *ceng ceng* playing rythmic ornamentation, the beat-keaping *kempli*, and a pair of hand drums called *kendang*. Four large gongs punctuate phrase structure. A single stringed bowed instrument, the *rebab*, and the *suling*, a flute, provide melodic ornamentation. Along with the gongs, the instruments we built were the main melodic instruments of the ensemble. These main melodic instruments include the *reong*, a set of kettle pots, and both the *pokok* and the *gangsa* which are similar keyed metal xylophones hit with mallets called *pangguls* [9].

2.1 The Pokok

The *pokok* are the melodic core played with rubber tipped wooden *pangguls*.

1) Jegogans- This pair is the lowest pitched set beside the gongs and covers the 5 tone pentatonic octave. It generally outlines key melody notes.

2) Jublags- The next pair up in range with slightly faster notes and playing a more complete subset of the melody. The jublags have 5 or 7 keys.

3) Penyacah- A pair of 7 keyed instruments above the jublags. These generally play along with the primary *ugal* melody.

2.2 The Gangsa

The *gangsa* provide melodic elaboration and are played with hard tipped wooden *pangguls*.

4) Pemade- Two pairs of two octave 10 keyed instrument that provide the mid-range.

5) Kantils- The highest instruments in the gamelan, harmonizing with the *pemade*. There are two pairs of these

6) Ugal- Also spanning two octaves with 10 keys, it is the only unpaired *gangsa*, generally linking with the *kendang* to lead the group. It plays the primary melody.

2.3 The Reong

Also spelled reyong, it plays melodic and rhythmic elaboration and is played with wooden sticks wrapped in string.

7) The Reong- Consists of 12 tuned kettle pots spanning just over two octaves. These can all sit on one frame or be split between two. Considered one instrument, it is played by 4 people with the higher octave usually doubling the lower. It is played similarly to bell ringing where an individual is responsible for only specific pitches within the melody.

2.4 Ensemble Play

Two major structural components of the music style are *kebyars*- very fluid unmetered and variable interruptions (literally to burst open) and *kotekans*-tight interlocking sections where the melody is formed by the combination of two separate parts [3]. The *gangsa* and *reong* are the primary *kotekan* instruments. For *kotekan*, players are paired rather than instruments with half the *gangsa* (excluding *ugal*) playing *polos* and half playing *sangsih.* Although the interlock is rarely as straight forward as single note-to-note on-beat, off-beat interlock, *polos* primarily centers around the beats with *sangsih* filling in the off-beat. Outside *kotekans*, *sangsih* usually plays the melody in a range above the *polos*. The *reong* often plays in *kotekan* with itself or plays unison rhythmic punctuations matching the rhythm section [9].

3. RELATED WORK

Gamelan has recieved little engineering attention. Aaron Taylor Kuffner, and Eric Singer, with LEMUR built the Gamelatron, a robotic gamelan orchestra [2]. The Gamelatron is a traditional set of instruments played robotically rather than a gamelan interface. Alternatively, Ajay Kapur has looked at custom percussion controllers for traditional instruments with the EDholak and ETabla [5]. These are Indian instruments but involve similar approaches applied towards different ends.

Meanwhile, electronic MIDI interfaces replicating traditional instruments are hardly a new thing. The first MIDI interfaces were keyboards produced in 1983 by Roland and Sequential Circuits. Originally intended as mere controllers, they were a clear mimic of the piano and quickly evolved to fully replicate the it's full range of interaction. 1984 saw Roland release the G707, a MIDI guitar controller followed by a MIDI only drum pad, the PAD8 'Octapad', in 1985 [7]. The flexibility of MIDI means it has been found commonly in new instrument interfaces ever since.

Gong Kebyar instruments are closest to xylophones and vibraphones in performance style although the damping techniques of both the *gangsa* and the *reong* are unique. The sustained ring of the natural instruments and the playing technique developed around it means damping is much more integral to the instruments. Alternate Mode's malletKat is the closest MIDI xylophone to fit the capabilities of gamelan. It uses FSRs (force sensitive resistors) to detect note onset and damping. It is also compatible with any mallet, matching a design goal to retain traditional playing feel including real *pangguls* [1]. Wernick uses piezos in its XyloSynth and is not mallet specific, but damping is based on time release [4]. Don Buchla's Marimba Lumina uses a very different approach based on radio frequency technology which enables capture of more playing style but requires special mallets [6]. None of these instruments were designed with gamelan damping techniques in mind and hence, none of them were sufficient for Elektrika.

4. ELECTRONIC GAMELAN DESIGN

Although Elektrika is intended for long term use, initial design and construction was for the premiere of Christine Southworth's "Super Collider" with Kronos Quartet at the Lincoln Center Aug 13, 2010. Part of Kronos's commission of the work was that it would be performed with electronic gamelan and, to improve touring viability, it should be a smaller ensemble. Hence rather than the full 24 instruments, the ensemble was reduced to 13 instruments: 4 *gangsa*, 2 *pokok*, 4 gongs, and a traditional rhythm section but with only one *kendang*.

Traditionally the *gangsa* and *pokok* parts are doubled. The instruments are paired and slightly out of tune with each other creating Balinese music's shimmering quality. Since the instruments are sampled, the idea is that one player can now trigger both pitches. This let us reduce the metalaphones to the minimum players.

The *gangsas* remain split between *pemade* and *kantil* with a *polos* and *sangsih* player for each section while the *pokok* is reduced to one *jublag* and one *jegogan*. *Penyacah* is often optional in traditional Gong Kebyar and was left out. There is also no *ugal*. There is no substitute for a full *reong*: two frames house 12 synthetic pots. The gongs, previously the most massive and heavy part of the ensemble, have been moved onto one significantly more portable frame.

The rhythm instruments have remained the traditional acoustic versions. There were never any plans to build a new hand drum interface for the *kendang* as commercial electronic drum systems are readily available. After testing a couple, they were not to taste, so we stayed with the acoustic originals. There were plans to build a *kempli* and, as the instrument is similar to a *reong* pot, it is not a significant technical challenge. However the *kempli* keeps the beat and is what players lock onto. It is preferential for its sound to remain centered within the ensemble and while slight latency or problems with another instrument can be dealt with, latency or missed notes on the *kempli* could be disastrous. A guaranteed anchor becomes especially important as the other instruments do not actually make noise. The *ceng ceng*, although desired, has yet to be built due to time considerations. Being a small ancillary instrument requiring a unique engineering solution, leaving it acoustic for "Super Collider" and augmenting it with a drum pad for the few synthetic sections was deemed acceptable.

There were a few dominant themes in the design goals for the instruments. As previously mentioned, the instruments should be lighter and more compact for travel. They should also retain as much of their original feel and performance technique as possible. Being able to use the normal mallets was preferable but not required. Meanwhile, the overall ensemble performance included the plan for instruments that could change samples and effects on the fly during performance but have to remain intuitive and understandable enough that the performers can still meet the demands of coordinating complex parts with the other performers.

4.1 Gangsa and Pokok Design

Focusing on the *gangsa* requires further discussion of playing technique. Proper playing of the *gangsa* (and *pokok*) involves striking the key with a *panggul* in the right hand while damping the previous note by grabbing the end of that key with the left hand. This creates the effect of one hand trailing the other. Musical texture can be varied by changing how long a struck note is allowed to ring and use of a "closed" hit meaning the key is damped while struck.

The *gangsa* have gone through two major design iterations. As fingers are used for damping, the initial design idea used in the first performance was to use a piezo to detect strike and strike velocity and a touch capacitive sensor to detect damping. First prototypes were made using acrylic but transitioned to cast urethane rubber keys. This was done as the rubber acts as a good acoustic dampener when hit by hard wood mallets and also has sufficient spring for good recoil. Casting also allowed the electronic keys to physically mimic the originals.

We used Vytaflex 20 for it's bounce and color, backing it with a 1/4 inch acrylic sheet. A large 1 inch piezo disc was centered on each piece of acrylic before casting and a copper plate added at one end. The piezo was sandwiched between the acrylic and the urethane while the copper capacitive plate resided underneath exposed to touch.

Figure 2: *Pemade* with rubber tipped *panggul*. Two FSRs between acrylic detect central strike and edge damping.

An Arduino Mega, able to support the analog inputs from upto 10 keys, was used to process the signals generated on the *gangsa*. Aside from light conditioning, the piezo signals from each key went directly to the chip analog inputs where they were polled. The capacitive signals were processed first using a single Atmel QT 1103 capacitive touch sensor which subsequently sent the digitized results to the Arduino.

Integrating the size of the piezo strike provided velocity. *Gangsa* and *pokok* are played one note at a time which also made cross-talk largely a non-issue. The strongest fastest signal is always the target signal. The capacitive sensing design was more challenging as the pad sizes were quite large (starting from 1 inch x 1 inch) and had to be tuned. When too sensitive, passing the hand near the sensor, as is a common in performance, triggered unintentional damping.

During construction and testing of the first gangsa design, we found that inconsistency in the casting thickness and piezo placing and adhesion, meant that velocity response was insufficently uniform and non-intuitive. Working with piezo discs, the adhesive and mounting significantly impact the quality of signal recieved so slight differences lead to comparative inconsistency. For an instrument made by hand, sufficient consistency is hard to achieve. Adding to this, the urethane damps too effectively. The physical hit does not propagate adequately throughout the whole key meaning that a hit far from the piezo registers more weakly than a hit directly above the piezo even though the physical force used was the same. A simple calibration test was devised using a ping pong ball dropped down a paper towel roll. Although detecting the strike was reliable and repeatable, the velocity sensitivity was not and deemed insufficient for use in performance.

These issues were addressed with a significant redesign after the first performance. To fix issues with velocity consistency, each key on a *gangsa* now uses an FSR sandwiched between acrylic with a second FSR to detect damping from a hand squeezing. Thin foam spaces the acrylic appropriately to the sensor size. FSRs can be slow to decompress and return to original state, an issue handled by use of a moving baseline. After considering playing styles, it was decided that the damping rate of the real instrument directly corresponds to the pressure with which it is squeezed and damping would be more appropriately detected through pressure. Conveniently, switching away from capacitive sensing resulted in more reliable damping, although frequent calibration was required while the new instruments settled. With the struck surface now hard acrylic, accoustic damping of the strike is achieved by attaching urethane to the *panggul* tip. Although a slight divergence from the intended goal to use unmodified *pangguls*, it is a minor modification not significantly changing feel.

The *pokok*, being similar in playing technique to the *gangsa*, have used the same designs adapted for correct scale.

4.2 Reong Design

The 12 pots of a real *reong* rest on strings providing bounce and enabling resonance. It has four players who each have two string wrapped *pangguls* and play single note melodies or chords. There are two primary styles of hit, the *byong* and the *chuck*. The *byong* is produced by striking the boss or nipple of the pot with the string wrapped part of the *panggul* and produces a clear pitched tone while the *chuck* is produced by hitting the flat part of the pot below the boss with the *panggul*'s hard wooden tip. The *chuck* is less tonal and more percussive.

Like the *gangsa*, the *reong* pots ring significantly and are damped for musical clarity and texture. Damping is achieved by direct pressure applied using the *panggul* with a technique of double hitting. The first strike is allowed to ring while the second, quieter damping strike sustains enough pressure to mute the original. In practice this is done very quickly and is hard to master. The *reong* also features a closed hit which is one that is never allowed to ring. Both *byongs* and *chucks* can be damped this way although the decay from a *chuck* is fast enough that damping is not as significant a concern.

The physical design of a *reong* pot is an acrylic mimic. A solid acrylic column topped with soft rounded Vytaflex urethane rubber is used for the boss and is mounted freely in a removable acrylic pot. A special rubber *chuck* pad sits in the pot edge. The *byong* column is kept in place by a base it slots into. Felt is placed between the column and the pot to eliminate contact sounds and ensure proper fit.

Byong strikes are measured using a piezo film placed within the base the column slots into. This enables the piezo to stay in a stable location. An FSR is co-located which is used to detect pressure and damping. The piezo response occurs faster than the FSR response and is easily tuned to capture a full range of velocities through signal integration. Using the FSR alone was not done as the column is tightly centered by the felt and the rest position and pressure from the *byong* column are not always consistent. Original tests also showed issues with dynamic range and the slow response of the FSR increased latency. The combination of the FSR and piezo has also proven very handy for identifying cross-talk. The *byong* sensors are sandwiched with foam and felt to provide some isolation from vibration transmitted through the frame and the column. Lastly, after the debut performance, it was found that the addition of a light weight disc spring isolates the column from the sensors, dramatically reducing cross-talk signals for much improved low-level sensitivity.

The *chucks* were originally built with a piezo film beneath a urethane pad combined with two FSRs in the pots rubber legs. The electronics will actually support four FSRs which could be used for position sensing but only two have been used so far. These sense pressure on the pot indicating the pot is damped.

During construction it turned out that the sensors are fairly delicate and would break easily while placed in the pot legs. Additionally, as with the *gangsa*, the urethane did not transmit the strike evenly so that the *chuck* velocity was strongly linked with where and how it was hit. After the debut performance, the piezo was removed and the two FSRs were moved to directly beneath the pad. Being more directly pressure sensitive, the FSRs remain largely cross-talk impervious. Using two FSRs enabled coverage for the full pad area and securing them under the pad is a less risky location for breakage.

Figure 3: One half of the *reong* holding six pots. The center is a free-standing rod with piezo films and FSRs placed underneath used to implement *byongs*. The small pads on the right are the *chucks*.

With up to seven inputs per pot, each *reong* pot has its own sensing engine. The piezo and FSR signals are run through operational amplifiers for gain control and maximum dynamic range before being analyzed using an Atmel Mega 88. Although initially interrupt driven, polling turned out easier and sufficiently effective. The latency for sending is under 7 ms with a 70 ms debounce hold after which it begins checking for damping.

Unlike the *gangsa* where cross-talk is easily ignored by selecting the peak signal, up to four of the six pots on a *reong* half can be played simultaneously. Additionally, a *reong* pot is uninformed of a neighbor's signaling and the sensors are affixed to the frame recieving signal propagation through it. The paired behavior of the FSR and the piezo enable the differentiation between cross-talk and a hit. With both the *byong* and the *chuck* in the case of cross-talk, the piezo response is timed significantly different from the FSR response. The column and the pot both being free standing, the FSR does suffer from cross-talk. With the *byong* column, the FSR signal is caused more from the column landing after a cross-talk induced disturbance so that it significantly lags the piezo response to the initial vibrations. The FSR signal also often rises before dropping as the column bounces.

Although each pot has its own MIDI out, for efficient cabling, each half of the *reong* also uses a Parallax Propeller to combine the MIDI streams on a frame for a single out. The Propeller, with eight parallel cores, turned out to be perfect for this task as a core could be devoted to tracking each of the six MIDI inputs and queing input messages in a stack to be sent out through an output core. This alleviated any concerns for collisions and means if the maximum of four pots are hit simultaneously, it adds a maximum of only 5 ms latency and guarantees no missed messages. The MIDI combining board also acts as a power distribution source for the other boards.

Figure 4: Gamelan Elektrika gongs being performed by Mark Stewart and Jacques Weissgerber. Rear mounted piezos discs are used to detect the strike while centered gold discs provide damping through capacitive sensing. *Photo by Kevin Yatarola*

4.3 Gong Design

After toying with a couple of novel designs it was decided to use the same sensing arrangement as the first *gangsas* for the gongs. Each of the four gongs have a piezo attached to a large acrylic disk to detect when it has been hit. Damping (not musically required but immensely useful as gongs have extremely long resonance) is done by mounting a large copper vinyl circle at the center. This is also visually suggestive of a gong. Again, the electronics are simply a reduced version of the original *gangsas.* As the strike surface is acrylic, the gongs do not suffer the same strike propagation issues. The inital design and construction proved itself well in the first performance and has only needed minor maintenance.

Structurally, the size and weight of the gongs have been dramatically reduced. Four large stands have been combined into one that holds four free swinging acrylic disks. Their sizes range from 9 to 12 inches in diameter, functionally matched to the real gongs according to their size.

4.4 The Brain

According to performance tradition where a musician is in full control of his sound, each player would be able to monitor and select sound banks locally. However in our case, individual control of a sound bank would be both a physical and mental challenge as the hands are fully occupied during a sitting performance. It seems appropriately Balinese to consolidate sample bank control in a central brain. Also, individual monitoring though highly advantageous, ends up either a cabling and mixing nightmare due to scale. A local synthesizer module is presently prohibitively expensive.

The result was a risky but necessary decision to generate all sound through one computer. The brain is a Macbook running Ableton which a musician uses to select sample banks in real-time. MIDI input boxes take 10 different instrument inputs and pass the MIDI note information on to Ableton. This has a disconcerting effect on a musician due to the lack of direct feedback from the instrument, replaced with the need to pick ”your” sound out of a full mix. Added to this, the sample bank may change without the musician’s input. Performance in this environment requires trust in the instrument behavior, low latency, and a different level of physical comfort than normal with a piece. Technical challenges aside, it was not certain from a musical perspective whether this would be a feasible performance environment.

5. RESULTS

Southworth’s piece ”Super Collider” successfully debuted as planned to an audience of over 5000 on Aug 13, 2010 at the Lincoln Center performed by Kronos Quartet and Gamelan Galak Tika using Elektrika. Apart from some issues eventually traced to electrical interference in cable runs, the final instruments worked largely as intended though they lacked velocity sensitivity. The decision to drop velocity was as much due to musicians inexperience with the instruments as technical challenges.

Kronos Quartet rejoined for a second performance on April 15, 2011, at MIT’s Kresge auditorium to a sold out crowd using the second version of the gangsas. This time there were no problems from the instruments. Improved instrument sensitivity and reliability plus rehearsal time enabled the return of instrument dynamics. Both performances were a success.

Rehearsals smoothed some of the disconcerting effects of sample bank changes and transpositions not triggered by the musician. The lack of local monitoring has displayed itself to be a challenge but is not insurmountable. An example of the trouble it can cause is there are times the *pemade polos* part is in unison with the *kantil polos.* If one player is slightly ahead or off, it becomes very difficult to know which player is actually the one ahead as there is no sound identification and correcting by trying to slow back a bit could just make the problem worse.

The ease of transistion from learning on the original instruments proves Elektrika’s success at being interchangeable with the real instruments but dynamics remain a challenge. A musician learns an instrument through feedback-hitting with a particular force produces a particular level of sound. For Elektria, sound systems and outside sources also effect volume, so a definite understanding is hard to come by especially without the chance to learn in a solo environment. Due to set up and rehearsal constraints this is yet to be mastered.

The redesigns for the second performance have yielded robust and satisfactory instruments. The instruments play consistently and sufficiently similarly to the originals. The gongs never needed much revision. The move to FSRs for the *gangsa* provides more expression at the cost of slight latency due to FSRs slow response time. Interestingly, the latency is small enough that musicians cope very quickly with it once aural feedback is available. Each time a new sound setup is used with different monitoring paths, the audible latency changes slightly regardless of the instruments. This requires learning new timing. At each new setup, the melody starts with a swing as interlocked syncopations are slightly off. However the section adapts and evens out after just a few minutes of sectional practice.

The addition of the disc spring after the first performance largely eliminated sensitivity limitations for the *reong byongs.* It is responsive and reliable. Now the question is

Figure 5: Gamelan Elektrika played by Gamelan Galak Tika during its premiere with Kronos Quartet at the Lincoln Center. The *reongs* and two *pokok* can be seen on the far side with the four *gangsa* and gongs on the left. The rear center features the accoustic percussion section, the computer "brain", and traditional gongs which Kronos Quartet played as part of the performance. *Photo by Kevin Yatarola*

whether the damped sound can be achieved using the same sample as the open hit. The move to two FSRs for the *chuck* works and has resulted in fewer torn sensors than the first design, but is otherwise not a major improvement.

6. FUTURE WORK

With the first two performances complete, Gamelan Elektrika is next bound for the Bang On A Can Summer Festival. It will be used in the composition course to teach gamelan and available for use by the students. Terry Riley, previously reluctant to write for GGT, has also been commissioned to write a piece for performance in the spring of 2012.

The second rebuild of the gangsas has settled well at this point and is now plug-and-play with no forseeable significant changes. The reong is due to move to a new larger frame that can effectively protect the electronics, presently exposed underneath. The *byong* has proven reliable, sensitive, and expressive and will merely require being rebuilt in the new frame. Switching to just FSRs to sense *chucks* for the second performance has resulted in a confusing mixture of latencies as the piezo driven *byong* is much more instantaneously responsive. During the rebuild, the piezo will be re-incorporated for consistent response time. To mitigate the directionality of force applied to the urethane, the pad will also be given a firm base so pressure applied anywhere on the pad can be equally detected.

Long term technological goals are to provide an in-ear monitor capability at each instrument, or instrument pair, enabling the musician to easily hear and distinguish what they are playing. There are also plans to finish the as yet undesigned electronic *ceng ceng* and the option of the electronic *kempli* in order to complete all the electronic instruments originally envisioned.

7. CONCLUSIONS

The Gamelan Elektrika instruments work. They achieve both primary design goals- a significantly reduced physical size and weight and a similar feel to the original. Through MIDI we have been able to meet the musical goals of variable tunings, wider sound palette, and easier transcription. The initial success even on immature instruments has been brilliant, and gamelan can now participate in the electronic age of music that other instruments entered years ago. For performers and musicians in the genre it is a freeing and exciting development.

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