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 possibilities 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 [4].

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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 pelog, presently the most popular form of gamelan and gangsa. These main melodic instruments include the reong, a set of kettle gongs, and both the pokok and the gangsa which are similar keyed metal xylophones hit with mallets called pangguls [10].

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

3) Penyacah- A pair of 7 keyed instruments above the jublangs. These generally play along with the primary agal 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 katekans-tight interlocking sections where the melody is formed by the combination of two separate parts [4]. The gangsa and reong are the primary katekan instruments. For katekan, 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 katekans, 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 [10].

3. RELATED WORK

Gamelan has received little engineering attention. Aaron Taylor Kuffner, and Eric Singer, with LEMUR built the Galtedron, a robotic gamelan orchestra [2]. The Galtedron 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 EHolak and ETaba [6]. 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 [8]. 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 dampening 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 pieces in its XyloSynth and is not mallet specific, but damping is based on time release [5]. 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 [7]. None of these instruments were designed with similar dampening 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 lets us reduce the metalaphones to the minimum players.

The gangsas remain split between pemade and kantil with a polos and sangsh player for each section while the pokok is reduced to one jublag and one jegopan. Pengacah is often optional in traditional Gong Kebyar and was left out. There is also no sangsih. 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 has 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 dampening 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 dampening. 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 its 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.

An Arduino Mega, able to support the analog inputs from up to 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 are polled. The capacitive signals were processed first using a single Atmel QT 1103 capacitive touch sensor which subsequently sent the now digital results to the Arduino.

Integrating the size of the piezo strike provides 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 insufficiently uniform and non-intuitive. Working with piezo discs, the adhesive and mounting significantly impacts the quality of signal received 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 dampening 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, acoustic damping of the strike is achieved by attaching urethane to the byang or hit. 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 baffle, it slots into. A belt 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 two 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 so far have been used. 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 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 pot legs. 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.

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 dampening.

Unlike with 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 uniformed of a neighbor’s signaling and the sensors are affixed to the frame receiving 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 queuing 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 the gold discs in the center 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 gangsa 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 circle at the center. This is also visually suggestive of a gong. Again, the electronics are simply a reduced version of the original gangsa. As the strike surface is acrylic, the gongs do not suffer the same strike propagation issues. The initial 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 Tik 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 gangsa. 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. The Boston Globe called the second “coolly exhilarating” [3] [should I cut the Globe reference?]

Rehearsals smooth 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 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 transition 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 this hard produces this level of sound. For Elektrics, system sounds and outside sources also affect 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. First, 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...
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 gangs and gongs on the left. The rear center features the acoustic percussion section, the computer "brain", and traditional gongs which Kronos Quartet played as part of the performance. Photo by Kevin Yatarola

largely eliminated sensitivity limitations for the reong byongs. It is responsive and reliable. Now there is just the acoustical issue 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 the group, has also been commissioned to write a piece for performance in the spring of 2012.

The second rebuild of the gangs has settled well at this point and is now plug-and-play with no foreseeable significant chances. 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 technical term 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.

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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9. REFERENCES