# Gyrotyre: A dynamic hand-held computer-music controller based on a spinning wheel

Elliot Sinyor and Marcelo M. Wanderley
Faculty of Music
McGill University
555 Sherbrooke St. West
Montreal, Canada.
elliot.sinyor@mail.mcgill.ca

## ABSTRACT

This paper presents a novel controller built to exploit the physical behaviour of a simple dynamical system, namely a spinning wheel. The phenomenon of gyroscopic precession causes the instrument to slowly oscillate when it is spun quickly, providing the performer with proprioceptive feedback. Also, due to the mass of the wheel and tire and the resulting rotational inertia, it maintains a relatively constant angular velocity once it is set in motion. Various sensors were used to measure continuous and discrete quantities such as the the angular frequency of the wheel, its spatial orientation, and the performer's finger pressure. In addition, optical and hall-effect sensors detect the passing of a spoke-mounted photodiode and two magnets. A base software layer was developed in Max/MSP and various patches were written with the goal of mapping the dynamic behavior of the wheel to varied musical processes.

## Keywords

HCI, Digital Musical Instruments, Gyroscopic Precession, Rotational Inertia, Open Sound Control

## 1. INTRODUCTION

While the sonic possibilites presented by computers are many, it is often hard to navigate them. One solution, as expressed by Joel Ryan, is to have "Physical handles on phantom models". He contends that a physical interface both "stimulates the imagination and enables the elaboration of the model using spatial and physical metaphors." [1]. Recent years have seen numerous examples of sensor-based digital musical instruments. A wide array of commercially available sensors and interfaces is readily available, and there is a growing body of literature discussing their use in digital musical instruments (DMIs) [2]. A shared goal of many sensor-based DMIs is to push forward the amount of expressive capability and real-time multi-parameter control which for electronic and digital instruments lags behind traditional acoustic and electric instruments.

The initial idea for the gyrotyre came from a desire to build a DMI based on moving parts, and to create mappings such that the musical output somehow mirrors the motion of the wheel. The important physical phenomena related to the *Gyrotyre* are gyroscopic precession and rotational inertia. Gyroscopic precession refers to the "wobbling" motion of a spinning object along its axis of rotation. A common example is the way the tilt axis of a spinning top slowly oscillates counter to the direction in which it spins. Rotational inertia refers to the tendency of the wheel to keep spinning once it is set in motion, which is useful for maintaining a relatively constant angular velocity. A subgoal of the project was to implement a physical sequencer track such that the rotation of the wheel corresponds to one measure, and that sensors placed around the track can trigger repeating musical events, such as drum hits.

## 2. RELATED WORK

Several publications deal with the use of dynamic mechanical devices to control media. In [3] the authors discuss several haptic devices used to browse and manipulate audio and video data. Most similar to this project are the *Big Wheel* and the *Haptic Clutch*. The *Big Wheel* is a motorized wheel that can sense hand pressure both parallel to the axle (eg. pushing down on a turntable) as well as normal to the axle (eg pushing on the rim of a turntable). The *Haptic Clutch* virtually models a set of wheels, one inside the other. By pushing down on the outer one, the inner wheel is engaged by a set of virtual "teeth" and moves with the outer wheel. Then, by removing pressure, the outer wheel can be disengaged while the inner wheel keeps spinning due to momentum. This controller can then be used by always applying pressure and moving the two wheels together slowly, or by setting the inner in motion and then quickly releasing pressure. The angular velocity of the inner wheel can then be used to control the playback position and rate of audio or video data. One of the mappings used by the *Gyrotyre* implements a similar idea.

## 3. DESIGN

### 3.1 Mechanical Construction

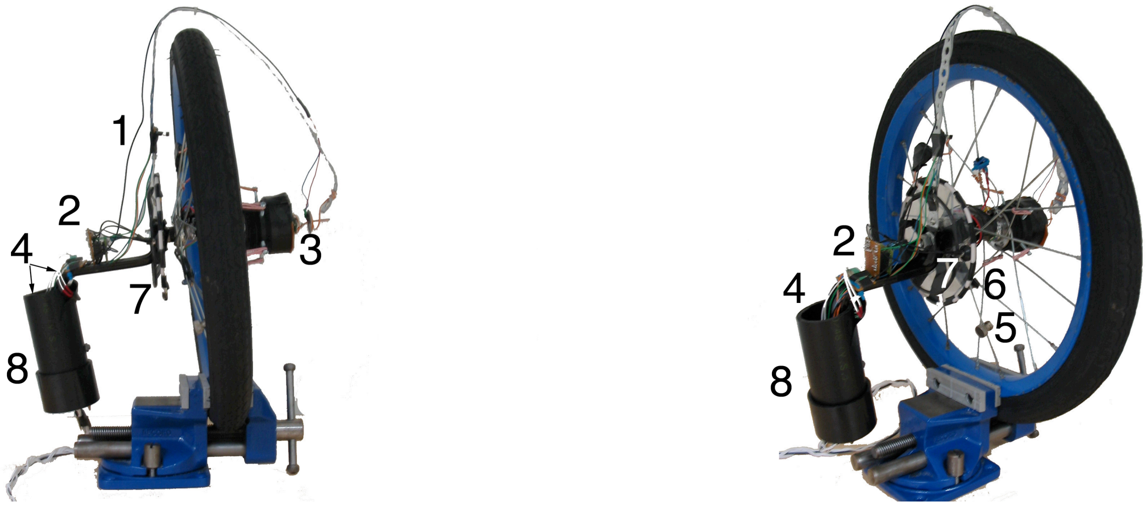


**Figure 1: 1. Hall-effect sensor 2. Two-axis accelerometer 3. Gyroscope sensor 4. Force-sensing resistors 5. Magnet 6. Photodiode 7. Optical Sequencer Track 8. Handle**

The *Gyrotyre* is based on the 30 cm front wheel of a child's bike. The tire was left on as it increases the rotational inertia when the wheel is spun. The handle is a 11cm section of ABS pipe attached by an L-bracket to the wheel's axle. A 51 cm strip of pliable aluminum was secured between the handle and the axle of the wheel and bent over the rim of the tire. This strip serves two purposes: (1) it holds the hall-effect sensor in place so that it is aligned with the magnets on the spokes and (2) it holds the contact with the gyroscope sensor on the other side of the wheel.

The PCB containing the gyroscope circuit is attached to a 5 cm section of ABS pipe which is attached to the spokes by elastic bands. The gyroscope circuit thus rotates with the wheel without touching the axle. The biggest challenge was mounting the gyroscope PCB such that it is completely centered on the axis of rotation, thus minimizing oscillations. The gyroscope contact, which can be seen directly above the number '3' in Figure 1, is attached to the metal strip via a piece of copper wire. This allows it to move with the gyroscope contact rod due to any off-center oscillations.

On the handle side of the wheel, a clear compact disc is attached to the axle such that it stays in place while the wheel turns. Two circular tracks of insulated heavy-gauge copper wire are affixed to the disc to act as a track for the infra-red recievers, which are placed inside plastic washers. The washers are held in place by the wires, but can be moved around the track so that they are triggered at different points by a spoke-mounted infra-red photodiode. Their physical spacing then corresponds directly to their temporal spacing when they are used to trigger audio events. The sequencer track can be seen in Figure 2. The handle also serves to hold the accelerometer, which is centered along the axis of rotation. It also contains two circular FSRs, one measuring 1.5 cm to be activated by the user's thumb, the other measuring 0.7 cm and activated by the index finger.

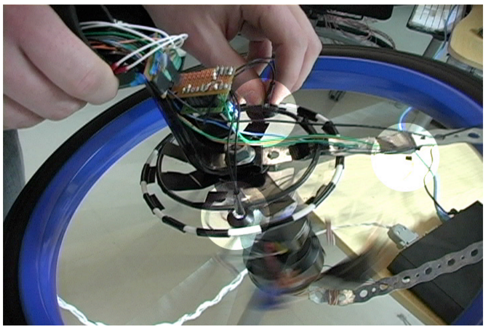

**Figure 2: Optical Sequencer Track. Two infra-red receivers and the hall effect sensor can be seen. The photodiodes and magnet spin along with the wheel.**

## 3.2 Electronics

Once again, the assembly of the gyroscope circuit presented the biggest challenge. Due to the fact that it turns with the wheel, the electrical signals going to and coming from the gyroscope could not simply be wired to the A/D converter. The solution was to have two separate power sources using the same ground. The A/D converter device provides the 5 volt signal and the ground for the "static" sensors (accelerometer, hall-effect, FSRs and infra-red detectors), while a 9-volt battery mounted inside the wheel provides power to the "spinning" circuit, comprised of the gyroscope and the infra-red emitter. Thankfully, the bearings and axle are conductive enough to provide the ground from the A/D converter. The gyroscope used is the Analog Devices ADXRS300 along with the ADXRS300EB evaluation board. The accelerometer used is the Analog Devices ADXL202 along with the ADXL202EB evaluation board. It was necessary to use 0.1 $\mu$F capacitor at the output which acts as an integrator and converts the duty-cycle modulated output to an analog voltage suitable for the A/D converter. The hall-effect sensor outputs a rising or falling edge depending on the polarity (and hence direction) of the magnet passing it. Similarly, each infra-red receiver voltage drops to nearly 0V when it aligns with the emitter. Finally, each FSR was put in series with a 68 k$\Omega$ resistor which acts as a voltage divider.

As an interface between the analog electronics and the

**Table 1: Sensors Used**

| | Sensor | Usable Range |
|---|---|---|
| Continuous | Accelerometer | -90 degrees to 90 degrees from horizontal |
| | Gyroscope | 0 to 0.83 revolutions/sec (300 degrees/sec) |
| | FSR | 30g to 10kg |
| Discrete | Hall-effect | > 3 rev/sec |
| | Infra-red | N/A |

software layer, the Ethersense was used [4]. The model used is capable of digitizing up to 32 channels of analog signals at a sampling rate of up to 1000Hz. It transmits the sampled data over ethernet using the Open Sound Control protocol [5].

### 3.3 Software

The software layer was built in Max/MSP. The guiding principle was to develop a layer that receives the incoming data and conditions it so that it can be easily used by successive layers. For the gyroscope data, this consisted of taking a moving-average over 5 values to counter noise due to bouncing. The first-order difference was calculated so that angular acceleration could be used as a parameter if desired. For the hall-effect sensor, an sub-patch was developed that outputs a bang when a magnet passes, as well as the width of the pulse, the time since the last pass and the angular velocity in degrees/sec. A similar object was used for the infra-red receivers. The output of the accelerometer was scaled so that it maps to [-1 1] along each axis.

Due to inherent design limitations, it is only usable for angular velocities of under 300 degrees/second (0.83 revolutions/sec), so while it was very accurate for that range, measurement of higher angular velocities requires the use of the hall-effect sensor. However, it was found that calculating the speed using the hall-effect sensors is only suitable for angular frequencies greater than approximately 3 revolutions/second, or 1080 degrees/second. As it stands, there are several drawbacks to using a the hall-effect sensor to measure angular velocity. The first is that the calculation requires the magnet to pass at least twice before it can report the speed. If the speed is increasing, the calculation is inaccurate and varies greatly between successive measurements. Also, if the wheel suddenly stops spinning, the software has no way of knowing unless a time-out is implemented. These issues would be partially addressed by adding several evenly-spaced magnets, or by using a rotary encoder with sufficient resolution.

## 4. TEST MAPPINGS

The following mappings were used to test the *Gyrotyre*:

### 4.1 Short-sample Sequencer

The infra-red receivers and hall effect sensor trigger short samples. For instance, in one configuration the hall-effect sensor triggers a bass-drum while one infra-red receiver triggers a hihat and the other a snare. By moving the receivers around, different beats can be created. The x-axis tilt angle controls sample playback speed while the y-axis changes the set of samples played. The thumb FSR controls volume. A looping mechanism was developed to record one or more loops of trigger data and play them back. This allows the user to record a drum sequence and then use a different mapping on top of it. The finger FSR acts as the record/playback button.

### 4.2 Noisy Synth

The gyroscope controls the main oscillator frequency, while the x-axis tilt signal increases the range of its control. In other words, for small tilt angles the maximum gyroscope velocity corresponds to several hundred Hz, while for large tilt angles it corresponds to several thousand Hz. This is somewhat analogous to "fine" control vs "coarse" control. The index-finger FSR controls volume.

### 4.3 Scrubber

This patch is useful for "scrubbing" long segments of audio, similar to using a turntable or jogwheel. Here, the "clutch" concept was used again in that when the finger FSR is pressed, the gyroscope determines the speed and direction, and when it is released, the chosen speed and direction are held constant. The "coarse" control concept is also used the playback speed is scaled by a factor of 1, 2, 3 or 4 depending on the y-axis tilt angle. The thumb FSR controls volume.

### 4.4 Omnichord

This was inspired by a 1980's musical toy from Suzuki in Japan that generates major/minor/7th arpeggios in various keys. The toy has buttons to choose the key and a linear "strumplate" (a small ribbon-controller) that plays the arpeggios in 4 octaves as the user strums his finger along it. The *Gyrotyre* version uses the gyroscope to determine how fast the arpeggios are played and the y-axis tilt angle to determine the octave. The index-finger FSR acts as a "clutch" ([3]) such that when it is pressed down, the gyroscope speed maps to the virtual speed and when the FSR is released, the speed stays constant until it is pressed down again, and the new arpeggio speed is determined by the new angular frequency. The key can be chosen from C, G, D, A, E, B or F, depending on the x-axis tilt angle. The direction of the rotation determines whether major or minor arpeggios are played.

### 4.5 MIDI score player

The angular velocity is mapped to the playback tempo of a MIDI score. The y-axis tilt value can add or subtract from the stored velocity values to allow for a certain amount of control over the dynamics.

### 4.6 Effects

This sub-patch is connected in series with the others in the signal chain so that it can be used to affect the output of any unit. X-axis tilt controls stereo panning, y-axis tilt controls bandpass-filter cutoff frequency, index finger FSR controls filter Q value, thumb FSR controls delay, and gyroscope speed controls reverb.

## 5. PERFORMANCE ISSUES

The prototype was used by one of the authors for a solo live performance, and by various other users for testing. It was found that the physical use of the wheel varies depending on the mapping used, or in other words, that the mapping defines the *essence* of the instrument [6]. Certain

**Table 2: Physical Modes of Use**

| **Mode** | **Physical Property** | **Relevant Sensors** (in order of importance) | **Musical Application** | **Example Mappings** |
|---|---|---|---|---|
| Fast spinning (> 1 rev/sec) | Precession | Accelerometer, hall-effect | Envelope generation, spatialization, dynamic control | 2,6 |
| Medium Spinning (between 0.3 and 1 rev/sec) | Rotational Inertia | Gyroscope, Accelerometer, infra-red, Hall-effect | Long sample playback, scales/arpeggios | 2,3,4,5,6 |
| Slow | Repetition | Infra-red, hall-effect, FSRs, Gyroscope | loop triggering, short sample triggering, long sample scrubbing | 1,3 |

**Figure 3: An example of performance. The sequence starts at the top right and continues clockwise. The mapping being used is the *Noisy Synth***

mappings, such as the noisy synth, encouraged users to try and find the extremes of the sensable range in order to produce feedback-like squeals. The arpeggio mapping, on the other hand, encouraged more subtle gestures, as the users attempted to remain in the position for a particular number of arpeggios before switching key or octave.

The use of the hall-effect and optical sensors to trigger samples was also successful. In addition to moving the receivers around to change the beat, the performer could also cover them or remove them from the track entirely in order to silence them. Changing the tempo is simply a matter of spinning the wheel at a different speed. With practice, it is possible to keep a steady tempo by gently tapping the wheel along for each revolution. Some users didn't even bother to spin the wheel, but rather positioned the optical sensors close to each other and moved the wheel back and forth to trigger them in quick succession. Table 2 summarizes the three main physical modes of use.

The mass of the wheel (roughly 1.5 kg) requires the user to expend energy, and thus the instrument requires physical effort to play. Due to the size, the audience can see the wheel spinning and hear the effect its motion has on the music, thus establishing a *transparent* [7] relationship between the gesture and the musical effect. Furthermore, the prototype was able to be used without looking at a monitor, allowing the user to forget that he/she is controlling a computer.

## 6. CONCLUSION AND FUTURE WORK

The spinning nature of the prototype provided both its most interesting features as well as the largest technical headaches. As mentioned above, centering the gyroscope sensor and obtaining the signal from it proved to be challenging, and while the solution works well, it is somewhat delicate. A future version would require a more reliable and durable method, such as machining an axle that can conduct 3 signals (5V, ground and sensor output), so that the crossover metal strip and battery are not needed. This would both decrease the weight of the system and make it capable of withstanding more vigorous use. Finally, a more durable and sophisticated sequencer track, containing beat markings and more triggers would also be an improvement.

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