

# Raja - A Multidisciplinary Artistic Performance

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## ABSTRACT

Motion-based interactive systems have long been utilized in contemporary dance performances. These performances bring new insight to sound-action experiences in multidisciplinary art forms. This paper discusses the related technology within the framework of the dance piece, *Raja*. The performance set up of *Raja* gives a possibility to use two complementary tracking systems and two alternative choices for motion sensors in real-time audio-visual synthesis.

## Keywords

raja, performance, dance, motion sensor, accelerometer, gyro, positioning, sonification, pure data, visualization, Qt

## 1. INTRODUCTION

Raja is a Finnish word and means border. We wanted to cross the border and tear down walls between interdisciplinary teams by joining technology and different art forms together. Raja is a new fusion example of technology, dance, sound design and computer graphics. It has been so far performed three times, in Tampere, Helsinki and London.

Human motion has been used to control sound in many different ways before. Commonly used technologies for detecting motion, position, proximity and gestures include camera based systems[3], light sensors, ultrasonic sensors[6], capacitive proximity sensors, piezo triggers, gyros[1] and accelerometers. The scope can be anything from tracking one solo performer to tracking large audiences[4]. The level of motion tracking varies from bistable acceleration triggers to accurate gesture recognition. The novelty in the Raja performance compared to other systems is the simultaneous use of two different tracking systems: motion and position. Also, there is a possibility to use both accelerometer and gyro for motion tracking. In the following sections the overview of the dance, the technical system, motion tracking and positioning technologies are presented. Strategies for sound synthesis and visualization are described in detail. The paper concludes with a presentation of outcomes and discussion about the future development of Raja.

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## 2. THE CHOREOGRAPHY

The choreography of the Raja dance performance for three dancers (Figure 1) was sketched by a professional choreographer in an iterative process. Initially, the choreographer was briefed about the possibilities of the technologies to be used. At this stage, the choreographer created the first version of the choreography, which was used as a basis for further development.



Figure 1: The Raja dancers.

In the second phase, the sensor configuration was selected: the dancers would each wear one motion tracker on their right wrist and one positioning tag in their hair. This selection had an impact into some details of the choreography. For example, the hand positions and movements were emphasized in order to provide a better signal for the sound synthesis. In addition, the movements of the dancers were modified so that their position on the dance floor would have a greater spread and variety. The first version of the sound design was also introduced.

The third version of the performance was modified from the second version based on feedback from the audience. The performance was divided into three parts where different sets of sounds were used to create an interesting contrast between the parts. The middle part was slow and peaceful with some improvisation. The performance ended with a short aggressive section where the dancers were dancing very intensively.

## 3. THE TECHNICAL SYSTEM

The technical configuration (Figure 2) of the system includes three laptop computers, networked together via an Ethernet switch. The indoor positioning, motion sensing and sound synthesis systems were each using their own laptop. In theory, everything could run in a single computer. However, to be able to monitor and control the different technologies at the same time, it was more convenient that each team had their own laptop.

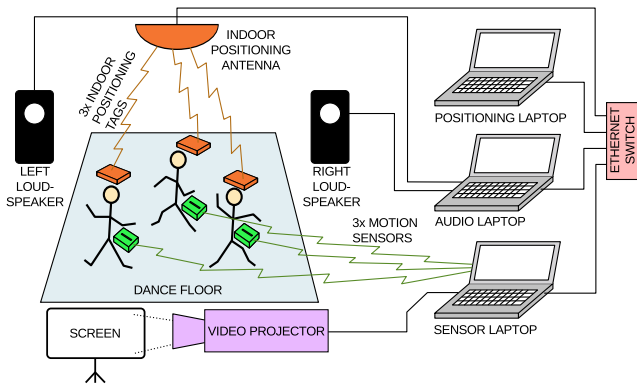


Figure 2: The performance system setup.

### 3.1 Indoor Positioning

High Accuracy Indoor Positioning (HAIP) technology developed in Nokia Research Center Helsinki Laboratory was used in the system[2]. HAIP provides position estimation of small battery powered transmitter tags by measuring the direction of the received UHF radio signals received by a receiver. The tags are worn by the dancers and the receiver is mounted above the dance floor. Several tags can be tracked with one receiver system. The accuracy of the positioning system is limited by the fact that the radio signal is blocked by the human body. Thus, the tags should preferably be mounted in the head area and the receiver should be mounted high up to have the best possible connection. In practice, the usable area is directly below the receiver so that the radius of the area is approximately 1.2 times the difference between the receiver and the tag height.

### 3.2 Motion Sensors

Ariane sensor-box motion sensors were used in the system. These are wireless sensor devices designed in the Advanced Systems Engineering department of Nokia Research Center. The sensor-box features accelerometer, gyro and magnetometer sensors, each with 3 axes. In addition they have two buttons, a light sensor, a barometer, a RGB LED, a vibro-tactile actuator and Bluetooth wireless connectivity. In Raja a  $4g$  range is used for the accelerometer and the range of the gyro is  $600^\circ/s$ .

For the reception of sensor data from the motion sensors, an application called *SensorPerformer* was implemented. This application includes the sensor processing algorithms, a network interface to stream motion sensor data out, a network interface to receive position data, a visualization engine and a sound engine. The application was coded in C++ using the Qt multi-platform application development framework.

## 4. SENSOR SIGNAL PROCESSING

### 4.1 Accelerometer

#### 4.1.1 Effect of gravity

The accelerometer was chosen as the motion sensor for the first version of the system. The challenge with an accelerometer for motion sensing is that it is also sensitive to the gravitational force. An algorithm was developed to remove the gravitation component from the sensor signal so that linear motion of the device could be used as the input to sound generation and visual presentation.

A device (Figure 3(a)) is affected by gravitational acceleration  $\mathbf{a}_g$ . Motion related linear acceleration  $\mathbf{a}_m$  sums to the  $\mathbf{a}_g$  to give a total acceleration  $\mathbf{a}$ , which is sensed by the

accelerometer. We are only interested in motion and thus, if we know the gravitation we can remove it from the sensor signal and we get  $\mathbf{a}_m = \mathbf{a} - \mathbf{a}_g$ .

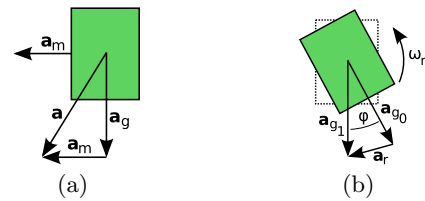


Figure 3: Total acceleration vector during linear movement (a) is the sum of gravitational acceleration and acceleration of the movement. Rotation (b) causes a change in the acceleration vector.

However, rotation of the device (Figure 3(b)) causes the gravity vector to change. In the initial orientation the gravitational acceleration is  $\mathbf{a}_{g_0}$  and after rotation of angle  $\varphi$  the acceleration is  $\mathbf{a}_{g_1}$ . Thus, if we at some point assume gravity is  $\mathbf{a}_{g_0}$  and remove it from the sensor signal to detect linear motion, after a rotation of  $\varphi$  the difference acceleration  $\mathbf{a}_r = \mathbf{a}_{g_1} - \mathbf{a}_{g_0}$ , is erroneously detected as motion. The magnitude of this error can be calculated as  $|\mathbf{a}_r|^2 = 2g^2(1 - \cos \varphi)$ , where  $g = |\mathbf{a}_{g_0}| = |\mathbf{a}_{g_1}|$ . A significant visible movement has an acceleration of  $\Delta|\mathbf{a}_r| = 0.2g$ , or more. An almost unnoticeable rotation of only  $\Delta\varphi = \cos^{-1}(1 - \Delta|\mathbf{a}_r|^2/(2g^2)) \approx 11^\circ$  results in such a change in the movement acceleration vector magnitude.

#### 4.1.2 Removal of gravity

The red trace in Figure 4 shows the magnitude of the total acceleration vector measured from the wrist during a short segment of dance. In the beginning there are slow moves which build up to an energetic section. One can see that the acceleration approaches the  $1g$  gravity in still parts.

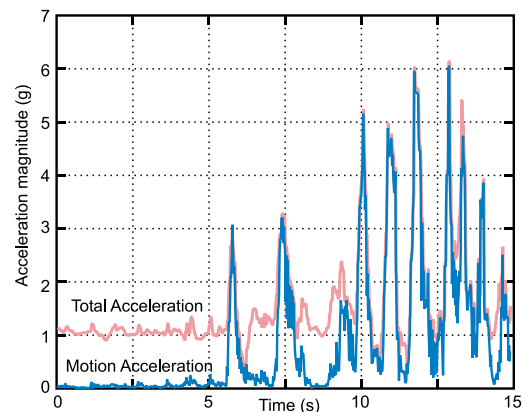


Figure 4: Accelerometer signal.

The removal of the gravity component is described in the diagram in Figure 5. Each orthogonal axis  $x$ ,  $y$  and  $z$  of the acceleration vector is processed identically according to this algorithm. First the estimated gravity is subtracted from the signal so that the acceleration caused by movement remains. This signal is low-pass filtered to reduce noise before it is differentiated for detection of change. A comparator checks if the change is above a fixed threshold.

In moments of stillness the change signal is below the threshold and a switch enables integration of the movement acceleration. This integrator output is the estimate of the gravity component as the closed loop with negative feedback

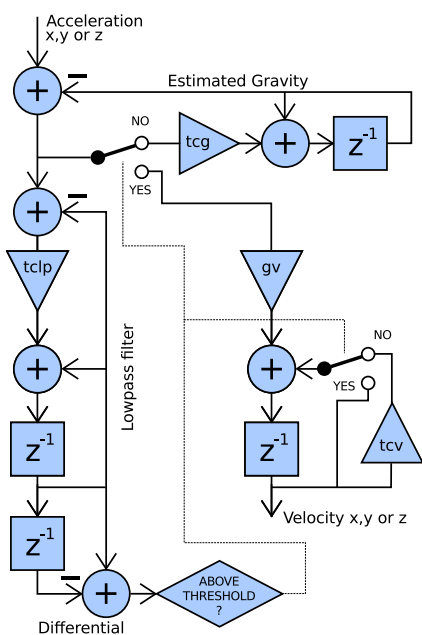


Figure 5: Gravity removal algorithm and velocity computation.

will settle so that the integrator input will be nulled. The blue trace in Figure 4 shows the motion acceleration, which is the result of gravity removal. It can be noticed that in most still moments the acceleration signal is now close to zero.

### 4.1.3 Computation of velocity

A velocity value is a more useful parameter because in most, if not all, natural sound generation processes the sound is related to the velocity of some mechanical part of the instrument, or air flow velocity in case of wind instruments. Acceleration happens mostly at the beginning of a move and at the end of a move, in the opposite direction. This would mean two separate signals for one sound gesture. By integrating the acceleration a velocity signal is generated with a smooth attack, sustain and decay.

During active movement the change signal (Figure 5) is above the threshold and a switch connects the motion acceleration signal to an integrator, which outputs a velocity value. In moments of stillness a switch leaks the integrator to reduce velocity offsets caused by asymmetry in the acceleration signal. Figure 6 shows the linear velocity computed from the acceleration shown in Figure 4.

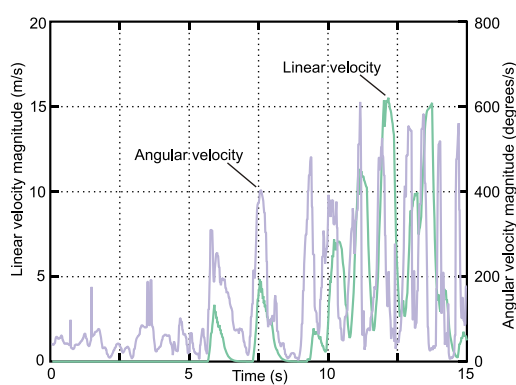


Figure 6: Velocity signal.

## 4.2 Gyro

We decided to use the gyro sensor instead of the accelerometer in the second performance set up as it is not influenced by gravity and the output is a velocity. We believed this would result in a more responsive and predictable sound representation of movement. The angular velocity trace in Figure 6 shows the gyro signal vector magnitude from the same wrist and performance as the accelerometer signals. Using the gyro signal was indeed found to be more responsive. A significant difference was observed, however, in the dynamic range. The gyro signal appears to be only little stronger during the energetic sections compared to the calm moments. We believe this is due to human physiology and motorics. Energetic movement results in only little increase in the rotational velocity of the wrist although linear acceleration can increase significantly.

## 5. AUDIO SYNTHESIS

The audio synthesis was implemented with Pure Data (PD). Sounds can be controlled by either angular or linear velocity, chosen independently between sensors. Three synthesized instruments were created, one for each dancer. The amplitude of each instrument is controlled by the vector magnitude of the velocity data so that the sound level correlates to intensity of movement.

The first instrument, *Frequency Synthesis Module*, maps musical textures with glassy, oscillating sounds. Eight digital oscillators' frequencies are controlled by the three velocity values from the 3-axis motion sensor. The 3-to-8 divergent mapping of the control signals is implemented so that each velocity controls each frequency with a certain weight. These weights were experimentally and artistically selected.

The second instrument, *Wave Module* is a polyphonic sampler with eight sample-voices. The magnitude of the velocity data applies parameter changes to the transformations of sampled sounds, controlling the playback rate of the polyphonic sampler. Resulted output implies dry, mechanical sounds with filtered pitch tonality.

The third instrument, *Sin Module*, is a frequency modulated oscillator. It generates a cosine wave with the amplitude controlled by an envelope generator. The magnitude of the velocity data is mapped to frequency and the envelope generator values. The output is streamed to a cosine waveshaper and filtered by a voltage controlled bandpass. The instrument generates brassy, sharp sounds with the dancer's movements.

In the third version of the Raja performance, a second set of instruments was introduced. The aim was to make this set towards more easy listening using classical instrument sounds. Piano samples were used for this set, which was used in the slower and more relaxed middle part of the performance, while keeping the electronic sound set in the beginning and end parts. The magnitude of the velocity data is scaled to integer numbers between 0 and 12. The generated values are mapped to MIDI note values in harmonic C minor scale.

Two separate background instruments were designed to support each section in the Raja performance. Both background instruments are sample based and create a dynamic rhythmic pattern. While the first background instrument creates certain tones continuously including the fundamental frequency in the piano section, the second one creates sounds containing inharmonic clusters of partials.

The positions of the dancers are mapped to the spatialization of each instrument. The system supports stereo or multichannel speaker systems. VBAP technology is used to control the direction of the audio stream in the perfor-

mance[5].

## 6. VISUALIZATION

An early version of the visualization was based on the idea that it would become a painting of the dance performance. Every movement and position of each of the dancers would be recorded in the painting and in theory the performance could be reconstructed from the painting afterwards. However, the visualization in this way was believed to be too chaotic for the audience to understand the correlation between dancers' actions and what was happening on the screen. To move closer to being a real-time illustration of position and movement the image was made to continuously fade away so that the more current graphical draw would stand out.

The final visualization design is implemented as follows. Three graphical objects of different color represent the three dancers. The positions of the objects on the screen are a direct mapping of the positions of the dancers on the dance floor. The objects can morph from a small dot to a large 8-bladed star when the dancers go from motionless to full motion. The star also rotates, with rotation direction and speed correlating with the sensed motion velocity. As a result each dancer is drawing a colored trace on the drawing canvas with size and texture matching the energy of the moves (Figure 7). And when the dancers stop, the traces fade away and only dots remain to indicate their position on the floor. The visualization was implemented using polygon drawing methods of Qt.



Figure 7: Visualization screenshot

## 7. THE EXPERIENCE OF THE DANCERS

We wanted to investigate how the dancers experienced the interactive sound production by asking them to fill in a questionnaire with three aspects: 1) implementation of the choreography when compared to a typical contemporary dance performance, 2) sensibility of the improvisation section and 3) the predictability of the sounds and implications of it on the dance.

From the dancers' perspective the main difference to a typical contemporary dance was the lack of the support from the music. Because it was missing, more communication between the dancers was required. Performing the movements simultaneously was more difficult because the synchronization had to be based only on visual communication between the dancers. On the other hand, missing time line of the music gave more temporal freedom in implementing the choreography, for example, the length of a pause.

The improvisation was considered to be the most pleasant part of the dance, especially because it used the classical piano sounds. After learning how the sounds respond to the movements, it was easier to modify the improvisation to produce certain type of sound patterns.

All the dancers mentioned that initially the sounds were somewhat irresponsive, predictability was weak and in some

parts the sounds were not in harmony with the movement. These concerns, however, were dispelled when the project proceeded.

## 8. CONCLUSIONS

Comparing gyro and accelerometer sensors it was found in practice that the gyro sensor was more responsive and predictable. However, the dynamics of the gyro was flatter. The accelerometer gave a better match between the energy of movement and energy of the sound. Gravity removal and velocity computation from the acceleration signal is approximate and the cause of the drawbacks of the accelerometer. Human physiology, on the other hand, is the probable cause of reduced dynamics of using the gyro. We are currently working on an improved algorithm using both gyro and accelerometer to achieve a solution with benefits from both sensors.

The approach to produce sound by movement was interesting for the dancers. They especially liked the improvisation part and experienced it as an additional channel to express movements. When the dancers got freedom to plan the movements together with the sounds, the overall experience became more harmonious. Thus, the choreography and the sounds should be designed in parallel.

One of the future directions to improve Raja is to enhance the sound-action strategies. By recognizing different types of movements and mapping that to a sound synthesis engine with a richer set of timbral and temporal parameters a more intriguing experience for both performers and audience can be created.

## 9. ACKNOWLEDGMENTS

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