PAPAGEI: AN EXTENSIBLE AUTOMATIC ACCOMPANIMENT SYSTEM FOR LIVE INSTRUMENTAL IMPROVISATION

Salman Bakht, Clarence Barlow†

UC Santa Barbara
Media Arts and Technology Program
† (and Music Department)

ABSTRACT

PAPAGEI (Parametric-Algorithmic Patchbay-Accompanist Generating Events by Improvisation) is an automatic accompaniment system based on the algorithmic music composition methods of Clarence Barlow and implemented by Salman Bakht. This paper describes the system design and implementation of PAPAGEI. Next, compositional and performance details are described for two pieces that use the PAPAGEI system: *resonancia flautomática*, by Clarence Barlow and *PIANO* 04h, by Salman Bakht. Lastly, the capabilities and limitations of PAPAGEI with respect to aesthetic results are described and potential additions to the system and future compositional possibilities are listed.

1. INTRODUCTION

PAPAGEI (Parametric-Algorithmic Patchbay-Accompanist Generating Events by Improvisation), an automatic accompaniment system, was developed initially for use in Clarence Barlow's improvisational flute and electronic piece *resonancia flautomática*, performed by Alan Fabian, Thomas Frey, and Christoph Seibert as part of the sixth annual COMPUTING MUSIC Concert Series held in Cologne, Germany on November 9, 2008. However, the system is designed to be flexible and extensible, allowing for compositional and performance experimentation by those with and without programming expertise. *PIANO 04h*, a second piece using the PAPAGEI system with MIDI player piano and human performer, was written by Salman Bakht and was first performed by Joann Cho at the Workshop on Media Arts, Sciences, and Technology at UC Santa Barbara on January 29, 2009.

This paper describes the system design and implementation of PAPAGEI. Next, compositional and performance details are described for the two pieces that use the PAPAGEI system. Finally, the capabilities and limitations of PAPAGEI with respect to aesthetic results are described and potential additions to the system and future compositional possibilities are listed.

2. SYSTEM DESIGN AND IMPLEMENTATION

The PAPAGEI software is written in C++ using the JUCE class library[1]. With minor variation, PAPAGEI uses the same functional model for each piece, as shown in Figure 1 and described below.

2.1. Signal Analysis

First, the instantaneous pitch and level of the human performer is determined. For monophonic acoustic instruments, such as the flute in *resonancia flautomática*, the performance is recorded via microphone to be processed in real-time. The instantaneous level is determined by finding the root mean square value of the windowed signal. The instantaneous frequency of the input is detected using a weighted autocorrelation function, a method particularly effective in high-noise environments [2]. The instantaneous frequency is mapped to the nearest semitone to give the instantaneous pitch. To avoid incorrect mapping of pitches (due to transients or detection errors), a new pitch is counted only after occurring for three simultaneous analysis windows, with a window size of 512 samples and 44100 samples per second.

If a MIDI instrument is used as is done in *PIANO 04h*, the instantaneous pitch and level are taken from the pitch and velocity of MIDI "note on" messages. In this case, multiple simultaneous pitches can be detected. However, the input must be separated into a set of melodic streams to be processed independently by the later stages. For example, with *PIANO 04h*, the lowest pitch at any instant is assigned to the first melodic stream, the second lowest pitch is assigned to the second melodic stream, etc.

The instantaneous pitch and level values are used to calculate a number of musical input parameters including pitch register, note density, melodic interval (from the previous note), and loudness.

2.2. Parameter Mapping

The system then maps the input parameters to inequivalent output parameters. For example, in *resonancia*

1 http://www.rawmaterialsoftware.com/juce/

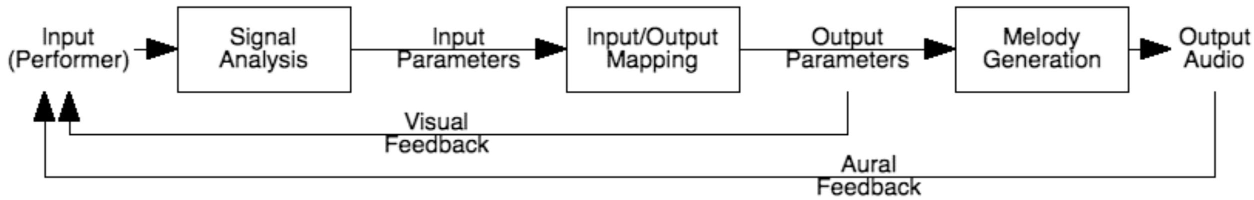

Figure 1. PAPAGEI functional model.

flautomática, an increase in the input's pitch register causes an increase in the note density parameter of the output. These assignments are performed at each pulse immediately before the melody generation stage. In some cases, the input parameter is linearly mapped to the output parameter ("outputDensity = scale * inputRegister;"), but the composer generally warps this mapping to provide a satisfactory result.

2.3. Melody Generation

When there is input detected from the human performer, an output melody is generated. First, the system determines whether a new note should occur on the current pulse. If so, a pitch and loudness (or key velocity in the case of piano) is chosen for this note. The algorithm for generating the melody and rhythm is based upon pitch and rhythmic theory developed by Clarence Barlow. These techniques are described in depth in Barlow's book, *Bus Journey to Parametron*[1] and implemented in his computer program AUTOBUSK. Below is a brief description of the process as used in PAPAGEI.

2.3.1. Rhythm

Rhythm is determined by a stochastic process dependent on the parameters of note density, metricity (metric field strength), and time signature. For a given time signature, a value called the "indispensability" is assigned to each pulse. These values correspond to the rhythmic strength of that pulse in the measure. For example, with a 3/4 time signature and four pulses per beat, the following set of 12 values are assigned to the series of 12 pulses: {11, 0, 6, 3, 9, 1, 7, 4, 10, 2, 8, 5}. Note that the strongest pulse, with a value of 11, is the pulse on the first beat.

The probability P of a new note occurring on a pulse is given by the following formula with D being density, I being indispensability, and M being metricity:

$$P = D + (I - 0.5) * M \qquad (1)$$

(When P is less than 0, the probability is 0, and when P is greater than 1, the probability is 1.)

2.3.2. Pitch

Pitch is chosen randomly using a function based on the tonic (keynote), melodic range, the previous output pitch, and degree of tonality. The melodic range is the maximum interval between the previous output pitch and the pitch of the note currently being generated. A probability table is generated for this range of pitches based on the current degree of tonality and the tonic. When there is a high degree of tonality, certain pitches closely related to the tonic (such as the tonic itself or an octave above the tonic) have a higher probability. When the degree of tonality is low, the probability of each note in the range is close to equal.

2.4. Output and Feedback

The computer-generated melody is generated either by an external MIDI device or by sample playback. This provides aural feedback for the human performer. Visual feedback is provided graphically on a computer screen as shown in Figure 2.

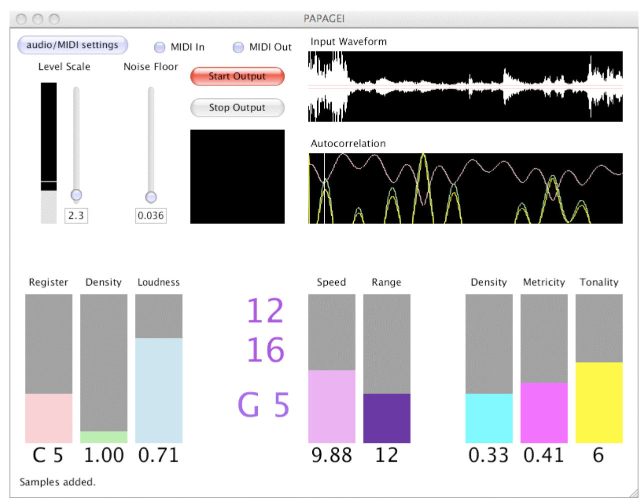

Figure 2. PAPAGEI primary user interface screen as used in *resonancia flautomática*.

3. MUSICAL COMPOSITIONS

As an improvisation system, the performances that use PAPAGEI are derived both by decisions of the composer and the human performer. In addition to general factors such as the instrumentation, the composer's decisions primarily concern the parameter mapping, which input parameters map to which output parameters and what the precise mapping function is for each pair. With the two performances that have occurred, the composers had very little additional input beyond ensuring that the human performer had a basic understanding of the parameter mapping.

3.1. resonancia flautomática

resonancia flautomática is a piece composed by Clarence Barlow. In this piece, the human performer plays the flute, and the accompaniment generated by PAPAGEI is played back with flute samples, with one sample for each pitch within the flute's range recorded earlier by the human performer. (A simple envelope applied to the samples allows for notes of varied duration.) The parameter mapping used is summarized in Table 1.

Input Parameter	Output Parameter	Relationship
Pitch	Tonic	Direct
Register	Density	Direct
Note Density	Metricity	Direct
Loudness	Tonality	Direct

Table 1. Parameter mapping for *resonancia flautomática*.

Additionally, the performer could increase the melodic range and speed (number of pulses per second) by performing certain melodic gestures. For example, playing three pitches each one or two semitones above the previous pitch would increase the melodic range by one semitone. As a result, these gestures become a defining characteristic of the improviser's performance.

3.2. PIANO 04h

In *PIANO 04h,* a piece composed by Salman Bakht, the human performer plays a MIDI player piano. The MIDI messages the performer generates are sent to the PAPAGEI system. PAPAGEI then generates an accompaniment, and the appropriate MIDI output messages are sent to the same player piano. The parameter mapping used for this piece is summarized in Table 2.

Input Parameter	Output Parameter	Relationship
Pitch	Tonic	Direct
Avg. Key Velocity	Velocity	Direct
Register	Metricity	Inverse
Key Velocity	Tonality	Direct
Width	Note Density	Direct
Number of Notes	Melodic Range	Inverse

Table 2. Parameter mapping for *PIANO 04h*.

This piece allows for multiple simultaneous input pitches. An equivalent number of output melodies will be generated up to a maximum of eight. Two input parameters that are used in *PIANO 04h* but not *resonancia flautomática* are number of notes and width. The number of notes is the current number of keys pressed by the human performer. The width is the interval between the lowest key and the highest key pressed by the performer.

The human performer begins by playing on the lower register of the piano while PAPAGEI plays on the upper register. By pressing certain keys on the piano, the human performer can trigger a change in position. Then the human performer would switch to the upper register and PAPAGEI would do the opposite. PAPGEI will not respond to keys pressed within the accompaniment's register, which allows the performer to play solo.

4. CONCLUSIONS AND FUTURE WORK

The accompaniment generated by the PAPAGEI system is not a successful simulation of a human performer. The system is memoryless on the scale of more than a few notes, does not consider any counterpoint rule system, and performs at a fixed pulse rate. However, as a system intended to accompany a human improvisational performer, the system is successful. While the human is able to adapt well to the output of the system and incorporate their musical skill and technique, the system suggests an alternative set of musical rules. The result is that the performance flows between a tradition developed by human performers and a new experience defined by the algorithmic system.

Still, there are a number of possible additions that could be made, allowing for a greater variety of pieces in the future. Specific plans for extension of the software include:

- Real-time (performance-time) segmentation of input audio for use in output sample bank.
- Implementation of stochastic methods for choosing between multiple output samples.
- Detection of timbral properties of input audio.
- Implementation of parametrically controlled audio processing of output.

When possible, existing audio analysis software packages will be used to add this functionality.

5. REFERENCES

[1] Barlow, C. *Bus Journey to Parametron, Feedback Papers 21-23*. Cologne: Feedback Studio Verlag, 1981.

[2] De la Cuadra, P., Master, A., and Sapp, C. "Efficient Pitch Detection Techniques for Interactive Music", in *Proceedings of International Computer Music Conference*, La Habana, Cuba, 2001.