GRAETLI: A MICROCONTROLLER-BASED DSP PLATFORM FOR REAL-TIME AUDIO SIGNAL PROCESSING

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ABSTRACT

This demonstration presents graetli, a standalone digital signal processing (DSP) platform for real-time audio applications, built around the Electrosmith *Daisy Seed* [1] microcontroller platform. graetli features high-quality analog audio I/O, a zero-latency analog dry signal path, a user interface with programmable potentiometers, and a rugged enclosure. graetli is suitable for both performance interaction and algorithm prototyping. To showcase its capabilities, we implement a frequency domain artificial reverberation algorithm. Conference visitors are invited to interact with the platform and experience the real-time DSP reverb algorithm.

1. INTRODUCTION

Software-based solutions for audio signal processing are very popular nowadays. Modern CPUs provide sufficient computational resources for audio signal processing, while high-level programming languages make development simple and agile. Despite the flexibility of purely software-based audio signal processing, many users still prefer interaction with physical hardware. Thus, standalone digital audio effects and digital music instruments are still common in the audio and music domain. Nowadays, this dedicated audio equipment is often based on modern microcontrollers, which provide sufficient processing power and can be programmed using high-level languages.

The *Daisy Seed* [1] by Electrosmith is an embedded microcontroller platform for audio projects (see Figure 1). Primarily, the platform features a powerful ARM Cortex-M7 microcontroller unit (MCU), a high-quality stereo audio codec, and an SDRAM (to buffer audio signals).[1] Combining the Daisy Seed with input/output buffers and a user interface (UI) results in a standalone programmable Digital Signal Processing (DSP) platform capable of functioning as either an audio effects unit or a musical instrument. Examples of such platforms include *Field* [2] by Electrosmith, *Dubby* [3] by Componental, or *Hothouse* [4] by Cleveland Music.

In this demonstration we present the graetli (shown in Figure 2), a DSP audio platform based on the Daisy Seed which features high-quality audio signaling, swift and neat UI, and a rugged enclosure. To demonstrate the capabilities of the graetli, we implemented an artificial reverberation effect.

[1]For the Daisy Seed, Electrosmith provides open-source tool chains in different programming languages and detailed instructions and accompanying examples for beginners: https://daisy.audio/software/.

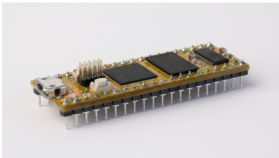


Figure 1: *Daisy Seed by Electrosmith.*

Figure 2: *graetli.*

2. graetli HARDWARE

A simplified block diagram of the graetli hardware is shown in Figure 3, with a more detailed version provided in Figure 4.

On a high level, the audio signal flow is as follows. The incoming stereo audio input signal is buffered by the preamplifier stages. On the Daisy Seed, the signal is then digitized by the codec, processed in real-time by the microcontroller (according to the DSP algorithm implementation), and converted back to analog by the codec. Finally, the output signal is buffered by the output amplifier stages. In addition to the audio processing, the microcontroller found on the Daisy Seed also manages the user interface and processes auxiliary control interfaces (MIDI I/O, control voltage I/O, expression pedal).

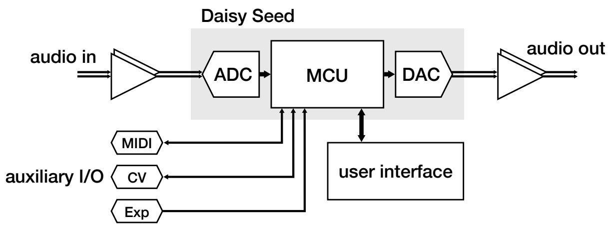


Figure 3: *Simplified block diagram for the graetli platform. The Daisy Seed's microcontroller (MCU) acts as the central unit.*

2.1. Analog Audio Inputs and Outputs

The graetli provides one stereo pair of balanced line-level inputs and stereo pair of balanced line-level outputs. The balanced inputs and outputs are also compatible with unbalanced setups, so the graetli can be integrated in various audio environments. As an alternative input, a high-impedance instrument input (mono) is also available, making the graetli compatible with passive instruments such as electric guitars. A dedicated headphone output is also provided, which is useful during DSP algorithm development and for standalone use cases.

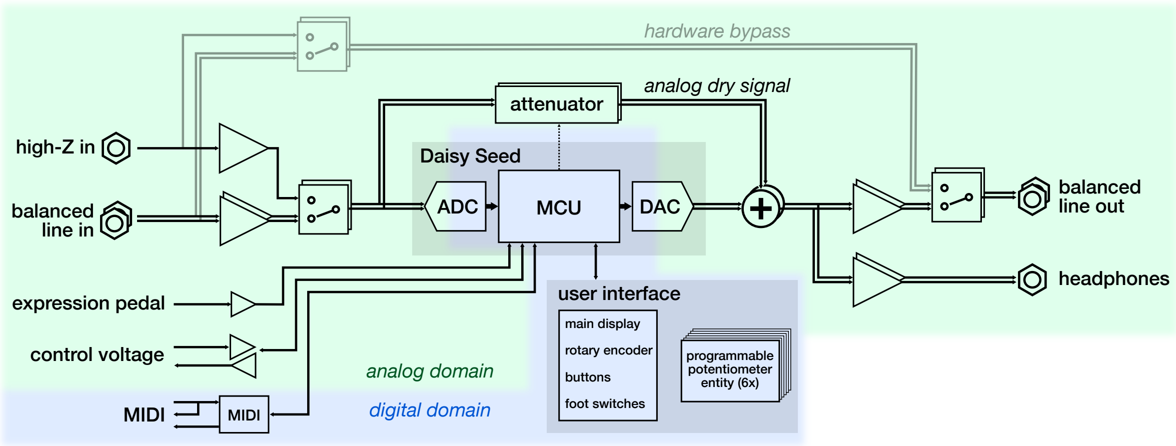


Figure 4: *Detailed block diagram for the* graetli *platform.*

The graetli features a *hardware bypass* mode that electrically connects the input and output sockets via switching relays. The hardware bypass circumvents any amplifier stages, analog-to-digital conversion, or digital-to-analog conversion.[2]

2.2. Analog Dry Signal Path

Latency is inherent in DSP systems and typically arises from two sources: the block processing the input signal, which introduces a variable amount of latency that depends on the block size, and the digital-to-analog and analog-to-digital conversion, which introduce a fixed amount of latency that does not depend on the block size.

To address this, the graetli, features an analog, zero-latency path for the dry signal (also known as *analog dry-through*).[3][4] As shown in Figure 4, the dry signal path bypasses the Daisy Seed entirely, which avoids the associated latency. Within the analog dry signal path, a variable attenuator is found, which allows for precise control of the dry signal level. The attenuator is implemented using a stereo audio attenuator integrated circuit [7], which provides an analog signal path while being digitally controlled by the Daisy Seed's microcontroller.

While the analog dry signal path is latency-free, the wet signal incurs a slight delay introduced by the DSP. This delay mismatch can lead to comb filtering artifacts. However, when implementing audio effects that intentionally delay the input signal — such as chorus, flanger, delay, or reverb — the delay mismatch can be integrated into the design to form an analog-digital hybrid signal path.

When phase coherence between dry and wet signals is critical, such as in distortion or dynamic effects, the analog dry path can be muted, and the dry signal can instead be routed entirely through the DSP.

[2]Note that the relay bypass is not a so called *true bypass*, since input sockets are connected to the pre-amplifier stages at all times. Implementing a *true bypass* would require even more switching relays and was thus avoided.

[3]The term *dry* signal refers to the unmodified input signal of an audio effect. Likewise, the *wet* signal refers to the processed effect output signal. In many cases, the eventual output signal of an effects unit is a mix of the dry signal (input) and the wet signal (effect).

[4]Two examples of effect pedals that feature an analog dry signal path are the Keely *Eccos* [5] or the Meris *Polymoon* [6].

Figure 5: *Top view of the* graetli *user interface. The depicted state shows the controls of a parametric three-band equalizer.*

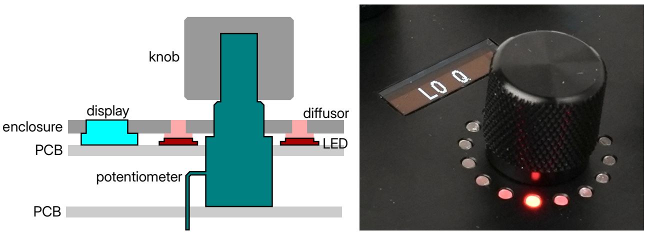
2.3. User Interface

The graetli's user interface was designed with the goal of swift user interaction and rugged hardware.

At the core of the user interface are six programmable potentiometer entities (Figure 5 right side), which allow the user to control up to 24 individual algorithm parameters without the need for menu diving. A detailed description of these potentiometer entities is provided in the next subsection.

Three foot switches[5] enable the user to switch modes and trigger actions while performing. Stored presets and additional configuration options can be accessed via the main display and rotary encoder (Figure 5, left).

[5]The selected model of foot switch features a medium actuation force, making them suitable for operation by foot or by hand.



(a) *Cross section diagram* (b) *Front plate view*

Figure 6: Sectional diagram and resulting view for the programmable potentiometer entity.

2.4. Programmable Potentiometer Entity

Many digitally controlled devices that support preset storage and use potentiometers for user interaction suffer from a common issue: When a preset is recalled, parameter values may change, but the physical positions of the knobs do not reflect these changes. This mismatch of visual feedback and actual parameter values can lead to poor user experience.

To address this issue, the graetli user interface features a group of six programmable potentiometer entities. Each entity consists of the following elements:

- *endless (rotary) potentiometer* - to read the user input
- *LED ring* - to provide visual feedback of the parameter value (substitute for knob indicator)
- *small OLED display* - to show labels or numerical values

The endless rotary potentiometers (further referred to as endless potentiometers) are an augmented version of standard analog rotary potentiometers. They differ in two key ways: First, the endless potentiometers do not exhibit mechanical end stops, such that the knob can be rotated indefinitely in either direction. Second, traditional potentiometers feature one wiper; the endless potentiometers feature two wipers which are offset by 90°. The offset wipers allow for continuous tracking of the knob's rotational position, without stops or deadband. The specific model used is *RV112FF* by Alpha [8].[6] The advantage of using an endless potentiometer over a rotary encoder is that the potentiometer provides a more tactile feel and finer angular resolution.

Each LED ring consists of 16 individual bi-color LEDs, each of which can be individually controlled to light up red, green, or yellow.[7]

The small OLED displays are placed directly above the LED rings and are used to show text labels (e.g., parameter names) or precise numerical values. The displays are $0.69''$ (17.5 mm) in diameter and offer a resolution of 96×16 pixels.

To harness the flexibility of the programmable potentiometer entities, the 6 physical entities are multiplexed to 4 virtual pages, for a total of 24 virtual potentiometers. Page navigation is handled via two dedicated buttons and four indicator LEDs located on the far right edge of the front panel (see Figure 5).

[6] This endless potentiometer is also used in the Focusrite *Scarlett 2i2 4th Gen* USB audio interface.

[7] Yellow is achieved through additive mixing of red and green

3. DEMONSTRATION ALGORITHM

To showcase the capabilities of the graetli, we implemented an artificial reverberation algorithm, based on the idea of a vocoder with noise as the carrier signal. Instead of the conventional filter bank, the modulated lapped transform (MLT) [9] is used. The resulting algorithm is similar to the frequency domain reverb described in [10].

The reverb algorithm is augmented with experimental features, including infinite-sustain (commonly known as "time-freeze" or "foreverb") and non-linear reverb (also known as *gated reverb*). Also, a time-domain equalizer is included to further shape the wet signal.

Thanks to its low computational complexity and moderate memory requirements, the algorithm is well suited for an embedded DSP platform such as the Daisy Seed. The CPU utilization was measured between 12.9% and 16.4%, depending on the MLT block size used.

4. VISITOR EXPERIENCE

The goal of this live demonstration is to show the audience the capabilities of an audio DSP platform, built around the Daisy Seed. In particular, we demonstrate the benefits of programmable potentiometers and the application of a zero-latency dry signal path.

Visitors can listen to the reverb effect, interact with the platform by adjusting parameters of the reverb algorithm through the hardware user interface, and explore a selection of presets. The input signal for the reverb effect is provided by a compact off-the-shelf synthesizer.[8]

5. REFERENCES

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