Simplifying Analogue Signal Processing into a Prototyping Toolkit

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This paper for *Beyond Prototyping Boards: Future Paradigms for Electronics Toolkits* proposes an analogue signal processing toolbox to simplify and accelerate the design process of prototypes that require an element of signal processing. Several different stackable modules are proposed, including an instrumentation amplifier, a Sallen-Key, a notch filter and a non-inverting amplifier. Based on the authors' experience with electromyography, an example implementation is given using the proposed toolkit. It is hoped that such a toolkit could reduce development time, minimise cost and aid in teaching signal processing and signal acquisition.

CCS Concepts: • **Human-centered computing → User interface toolkits**.

Additional Key Words and Phrases: Prototyping, Analogue Signal Processing, Electromyography, Functional Electrical Stimulation

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1 INTRODUCTION

Our focus in this contribution to the *Beyond Prototyping Boards: Future Paradigms for Electronics Toolkits* workshop is to describe kit designs that can make analogue signal processing accessible to anyone wishing to prototype electronics hardware ideas, without having to design and build such systems from scratch, like how Arduino boards and shields remove the need for designing and constructing PCBs for discrete electronic components. Signal processing - both analogue and digital - are essential for data acquisition, with applications ranging from medical electronics to audio processing. A raw unfiltered signal (such as a signal from a microphone) will have noise and other artefacts (such as mains hum) that distort the signal, resulting in a poor quality result. Signal processing is conducted using filters, which remove specified frequencies (the frequency of the noise) from the signal. While these filters are fundamental to signal processing, their design can require a high degree of familiarity of control theoretic concepts, with analogue filters in particular also requiring expertise in electronic circuit design, making signal processing a specialised field. Due to this complexity in the design and construction of filters, little work has been done to make signal processing accessible to an audience interested in exploring electronics - despite the significance of this tool. There is a particular gap in analogue signal processing (ASP) which completely lacks a quick, modular form of prototyping, while tools such as the scipy.signal[1] Python package have simplified the design of digital filters. This paper offers solutions to the problems of ASP, with the ultimate aim of making this technique easily accessible without the need for advanced knowledge in mathematics and electronic circuit design.

[1]https://docs.scipy.org/doc/scipy/reference/signal.html

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2 MOTIVATION

While we are interested in the educational value of the kit we are proposing, there is also a value of the approach for enabling more rapid prototyping across a range of devices. For example, the authors have 18 years' experience developing assistive and rehabilitative technologies (ART). A key focus is stroke, the second highest cause of disability worldwide, and our research addresses the problem that 60% of people with stroke fail to regain arm function. The range and variability of user physiologies, combined with the time constraints of clinical testing, mean that rapid prototyping tools are key to developing solutions that are accepted and valued by PwS. Having plug and play filters for prototyping makes it possible to do more near real-time adjustments to devices for evaluation. For HCI this encapsulated hardware approach means that designers can realise co-designer/stakeholder feedback more quickly. In the sections below, we highlight this example in the use of electromyography (EMG) in ART terms of the value/role of our proposed components.

EMG is used extensively in ART, particularly within biofeedback and robotic therapy [2]. EMG captures volitional effort and is used by ART to improve task training and to provide motivating feedback. EMG is a small signal ranging from 0-10mV [4], and is therefore susceptible to several forms of noise, such as cable/electrode movement artefacts that produce low frequency noise (less than 10Hz) and 50Hz/60Hz mains noise. Therefore analogue filters are needed to amplify and extract the useful information while reducing noise, with filter parameters depending on the user physiology, electrode placement and environmental conditions [7]. However, commercial EMG systems use fixed, conservative values, which lose valuable data. A platform that enables filters to be rapidly modified and tested is hence of significant value to the field.

The need for flexible, rapid prototyping solutions increases when EMG is combined with functional electrical stimulation (FES), a core focus of the authors' work. FES is the most commonly used ART and assists weak or impaired movement by artificially activating muscles [2]. FES involves placing electrodes on the surface of the skin and applying pulses of electrical current which pass through underlying nerves, thereby causing the muscles to contract and generate movement. When carefully controlled to assist goal-orientated, functional movements, the stroke user is able to rebuild neural pathways and recover their lost movement. Effectiveness of therapy correlates with the accuracy that FES supports the voluntary intention of the user. EMG has long been used to trigger predefined FES sequences in response to EMG reaching a preset threshold. This requires only basic processing [4], and has led to several commercial devices (e.g. Neuromove NM900, Zynex Medical, CO, USA). More sophisticated approaches use the entire EMG signal within a closed-loop control system, improving clinical outcomes but increasing processing demands.

Recent research has maximised effectiveness by measuring EMG from the same muscle that is stimulated by FES [6] using artificial neural networks and learning control. They require more filtering stages and parameter selection to remove the electrical contamination caused by the far larger FES signal [8]. As with basic EMG processing, parameters are patient-specific and vary over time, motivating the need for analogue filtering systems that can be rapidly tuned in clinical environments.

3 SIMPLIFYING ANALOGUE SIGNAL PROCESSING

3.1 A Prototyping Toolkit

Referencing the paradigms detailed in [1], ASP can be transformed from a type (1) paradigm that requires knowledge of discrete electronic components into a type (3) paradigm, which would be a toolkit containing several filter modules that are designed to work together. To achieve paradigm (3), we propose several small PCB active filter modules that are designed to stack together to create a fully functioning signal processing system that still offers a high degree of customisation by the user, but without all the issues associated with building circuits on breadboards or designing PCBs.

As many ASP topologies are already well defined and documented, the process of designing active filters for signal acquisition has been simplified to a few topologies (mainly the Sallen-Key topology). This has also resulted in a simpler set of mathematical equations to compute component values for the desired gain/cut-off frequencies, with several online calculators that perform this task, such as this Sallen-Key filter calculator[2] and this Twin-T Notch filter calculator[3].

A collection of these breakout board modules that allows the user to configure the resistor/capacitors values to control the gain and filter characteristics would remove the need for a breadboard. These modules could be designed to stack with each other, forming a simple toolkit. A web application could then be utilised by the user to generate the capacitor and resistor values needed to achieve their desired filter response, but with more options, such as the choice of higher order Butterworth or Chebyshev type I filters (which can both be built using the Sallen-Key topology). Both these tools combined removes the need for electronic prototyping through breadboards or PCB design and assembly, and it also removes the use of mathematics or CLI/programming tools such as Matlab/Octave/SciPy.

3.2 Breakout Board Modules

We propose four fundamental breakout board modules, with all of them using active electronic components. All these modules take in a reference voltage, power, ground and the signal that is being filtered. The modules also output all these values, allowing another module to daisy chain onto a previous module, taking in all the power inputs from the previous module, as well as the filtered signal.

Instrumentation Amplifier Module: This module takes an input from a differential signal, subtracts and amplifies it. The user is able to configure the gain of the amplifier through a potentiometer on the breakout board. This board could support multiple input methods for the signals, such as header pins or an audio jack.

Sallen-Key Module: All the resistors and capacitors (2 of each) can be configured on the Sallen-Key module, by using dual in-line (DIL) sockets that allow the pins of through-hole passive components to be inserted into the socket. This allows the Sallen-Key to be configured as a 2^{nd} order Butterworth high pass or low pass filter. Multiple Sallen-Key modules can be used to build higher order Butterworth or Chebyshev Type I filters.

Notch Filter Module: This is an active Twin-T Notch Filter for removing noise at a specific frequency. Due to the number of passive components required to get a specific frequency, the filter frequency is not configurable, so two versions of the module would be available - 50 Hz and 60 Hz for removing mains noise. However, the Q-factor of the notch filter can be configured through a potentiometer.

Non-inverting Amplifier Module: This module contains a non-inverting operational amplifier with the gain being set via a potentiometer, allowing the user to configure the voltage amplitude of their signal.

3.3 Applying the Toolkit for EMG Signal Acquisition

Based on the EMG signal characteristics described in section 2, Figure 1 demonstrates how an EMG amplifier could be created using our proposed toolkit. First, the differential input from two electrodes positioned on a muscle (with a third reference electrode placed on a bony landmark) is amplified through an instrumentation amplifier - with a gain of 10 - removing common mode noise. This signal is then passed through a high pass filter to remove the movement artefacts, and then passed through a notch filter to remove mains noise. To prepare the signal for sampling, it is passed through

[2] https://www.daycounter.com/Filters/Sallen-Key-LP-Calculator.phtml
[3] https://www.changpuak.ch/electronics/Active_Notch_Filter.php

a low pass filter to remove any higher frequency components, and then amplified another 50 times to get the signal within the order of a few volts. The signal can then be sampled by an Analogue-to-Digital Converter at a minimum sampling frequency of 1kHz.

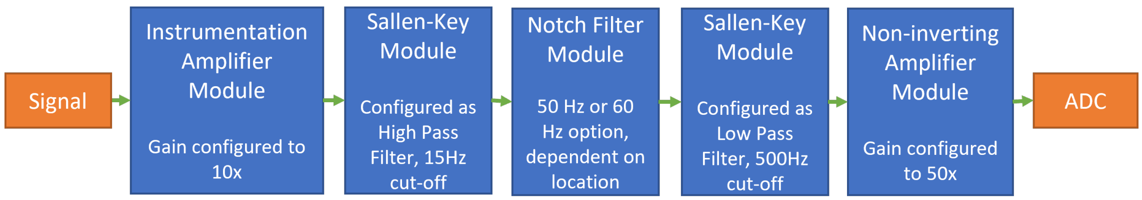

Fig. 1. An EMG amplification circuit using the proposed toolkit

4 CONCLUSION

Based on our experiences within biomedical electronics, we have proposed a modular toolkit that could simplify the prototyping process by streamlining the implementation of analogue filters, removing the need for specialised knowledge. As well as the EMG/FES applications mentioned in section 2, other bioelectronics applications include electrocardiograms, electroencephalography [5] and strain sensors for muscle contraction monitoring [3]. Audio processing is another application that could benefit from a modular ASP tool kit, which could allow for a simpler way to experiment and create audio synthesizers.

Just as the Raspberry Pi[4] and Arduino[5] have opened up electronics prototyping to non-engineers, we see this kit as a way to make electronics more accessible - not least within the HCI / Tangible User Interface communities. Our vision is for such a toolkit to be open sourced and further expanded by the community through the creation of more filter modules, to support a broader range of educational, prototyping and interactive design opportunities.

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