A FLEXIBLE USER INTERFACE FOR RAPID PROTOTYPING OF ADVANCED REAL-TIME MYOELECTRIC CONTROL SCHEMES

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ABSTRACT
A recent emphasis on the advancement of upper limb prosthetics, due in part to the high number of injuries resulting from ongoing military conflicts, has accelerated research in the field of advanced prosthetics. One important aspect of the controls portion of this research is the ability to quickly transition from experimental algorithms to control schemes which can be used and tested in real time by end users. Herein, the authors introduce a powerful Matlab-based software package which facilitates rapid prototyping and testing of novel real-time control schemes. The ACE (Acquisition and Control Environment) application has recently been used as a research and clinical tool, helping to verify the viability of existing myoelectric control strategies, and is helping to accelerate the development of novel control schemes.

BACKGROUND
Since the 1960’s, the research community has demonstrated an ability to classify muscle contractions using pattern recognition of myoelectric signals (MES) [1]. Until recently there has been a substantial disconnect between the results of published myoelectric control research and clinical practice. Most applications of myoelectric control in the clinic have consisted of single and dual site MES amplitude-based control strategies [2]. While these approaches have worked well for existing prostheses which typically consist of one or two actuated degrees-of-freedom (DOF), it is evident that more advanced control schemes will be required to operate the many DOFs being built into next-generation prostheses. Pattern recognition has repeatedly shown the capacity to discriminate between many classes of motion [1] and, as such, is a logical candidate. The challenge becomes a matter of bridging the gap between theoretical, offline research and a real-time, clinically viable solution. This not only indicates a need for a real-time implementation of pattern recognition based myoelectric control, but also a presentation style which can be accepted by, and mutually beneficial to, both the research and clinical communities.

The clinical purpose of the ACE software package is to provide an intuitive suite of tools that a clinician can use on a case-by-case basis in order to create an optimal user-specific control configuration. ACE builds on clinically accepted practices, leveraging tried-and-true approaches while adding functionality through the use of signal processing and pattern recognition.

As a research tool, ACE provides a much needed venue for quickly and effectively comparing signal processing algorithms and control schemes in a real-time environment with direct user feedback. The adoption of ACE as a research tool has allowed for the standardization of data collection and testing protocols between research partners, encouraging collaboration and accelerating research and development efforts.
SYSTEM ARCHITECTURE

The ACE software architecture consists of four main components: signal acquisition, input configuration, control configuration, and visualization. These distinctions maximize modularity, enabling modifications to be made to any one aspect of the architecture with minimal impact on the rest of the system.

Signal Acquisition

Signals are acquired using an external multi-channel data acquisition card (DAQ). To date, various 8 and 16 channel Measurement Computing and National Instrument cards have been used; however, any card supported by the Matlab Data Acquisition toolbox can be integrated with minor changes to initialization files. A custom built pre-amplification system, with configurable gains, connects the DAQ to input devices such as electrodes and electro-mechanical inputs (joysticks, switches and force sensitive resistors). Real-time visualization displays provide valuable feedback (both during initial configuration and during real-time use) about signal integrity and quality.

Input Configuration

Input configuration in ACE refers to any signal processing of inputs before they are used by the control configuration. The purpose of this component is to optimize the available information, as well as perform any processing required to consolidate all inputs into a common format for use in control.

User definable parameters are used to select desired filtering, pre-processing and post-processing algorithms. If pattern recognition is to be used, data collection, classifier training and testing is performed at this point. Once completed, the configuration is applied, and any further reference to pattern recognition is done through the use of ‘virtual channels.’ A virtual channel is the term used to describe a given class output from a classifier. The virtual channel associated with the active class decision is assigned a proportional control value (obtained by calculating some function of the amplitude of the channels used as inputs to pattern recognition). All other virtual channels are assigned values of zero. In this way, pattern recognition outputs are modeled in a way that is very similar to conventional MES sites, which are small in amplitude when the underlying muscle is inactive and proportionally large when the muscle is contracted. This designation allows pattern recognition outputs to be used interchangeably with other conventional MES and electro-mechanical inputs for control.

Control Configuration

Because of the virtual channel masking performed in the previous stage, the configuration of control schemes can be done with minimal regard to the source of the input signals. With that in mind, ACE

![Figure 1 – An example of the ACE real-time DOF configuration window in dual site mode]
provides a selection of single and dual site control options, all of which are taken from common clinical practice [2]. These control modes allow the clinician to map one or two inputs to the actuation of a DOF using amplitude or rate sensitive control schemes. Figure 1 shows a dual site configuration being tested in real-time.

Using these control modes, it has been found that in many circumstances virtual channels actually alleviate some of the clinical difficulties which arise during control configuration. Because single classifier outputs are mutually exclusive in nature, they are not subject to muscle co-activation/crosstalk which can sometimes hinder conventional amplitude based control schemes.

**Visualization**

A large portion of the user interface architecture in ACE is composed of visualization tools. As a clinical tool, it is imperative that clinicians have feedback about signal quality and control efficacy. As a research tool, the insight that can be gained by viewing tangible results in real-time is invaluable. As such, ACE includes many standard visualization screens such as the raw signal viewer and control configuration screens mentioned above. A virtual channel viewer is modeled after the raw signal viewer, displaying proportional classifier outputs in real-time. ACE also contains research oriented tools such as a two dimensional representation of multi-dimensional feature space for viewing features in real-time. Another screen displays classification boundaries in real-time, for use in ongoing online adaptive classifier research. These tools, among others, have helped increase understanding of real-time pattern recognition based control and reinforced the need for ‘user-in-the-loop’ controls research.

Also included are two virtual environments, which incorporate timed and task oriented usability tests. The feedback from these tests has been very useful for comparing control schemes and tracking user progress. ACE is also able to drive various electro-mechanical outputs, using the DAQ output interface included with the Matlab Data Acquisition toolbox.

**REAL-TIME DATA FLOW**

Figure 2 depicts the flow of data during real-time operation in ACE. Using the configuration interface, parameters within each of the component blocks can be configured for a particular clinical or research purpose. The modular depiction of these blocks represents their explicit separation within the application code. This has allowed researchers to quickly and efficiently test new algorithms by adding to or replacing particular functionality.

![Data flow diagram through ACEs real-time control engine](image)


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ACE IN THE CLINIC AND IN THE RESEARCH LAB

The ACE application has recently found substantial use, serving as the basis for other developments, as well as a valuable research tool. Following are some of the projects which have benefited from the use of ACE:

- A version of ACE was used as the starting point for the development of the configuration interface of the DARPA funded Revolutionizing Prosthetics 2007 project.
- A portion of ACE is being used to configure pattern recognition in the Virtual Integration Environment of the DARPA funded Revolutionizing Prosthetics 2009 project, led by Johns Hopkins University. [3]
- ACE has been used extensively as a clinical and research tool at the Rehabilitation Institute of Chicago [4]
- ACE is continually evolving to support several research streams at the University of New Brunswick. Serving as the main research environment, it has been instrumental in the development and testing of novel classification algorithms and control schemes [5-8]

CONCLUDING REMARKS

In an effort to help bridge the gap between research and clinical practice, the ACE software package combines proven control schemes with leading edge signal processing. The modular architecture has allowed for rapid prototyping of new signal processing and control algorithms and support of real-time testing. Clinical and research groups have used ACE as a forum for collaboration, resulting in shorter development times and a greater understanding of real-time myoelectric control.

REFERENCES