AWARD NUMBER: W81XWH-16-1-0767

TITLE: Workflow Optimization for Tuning Prostheses with High Input Channel

PRINCIPAL INVESTIGATOR: Daniel Merrill

CONTRACTING ORGANIZATION:
Ripple LLC

Salt Lake City, UT 84109-2319

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TYPE OF REPORT: Annual Report

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

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6. AUTHOR(S)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Ripple, LLC
2056 S 1100 E
Salt Lake City, UT 84106-2319

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This program will develop a control system that provides amputees outfitted with high-channel-count myoelectric signal monitoring systems, simultaneous use of multiple degrees of freedom (DOF) of a prosthetic limb. The program will also develop software and hardware tools prosthetists can use to adjust controller behavior to maximize limb function for each patient. The main strength of this program is that it combines basic research with existing, proven technology to provide novel rehabilitation strategies that meet a critical need in the military and civilian upper-limb amputee population.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			USAMRMC
Unclassified	Unclassified	Unclassified	Unclassified		19b. TELEPHONE NUMBER *(include area code)*

TABLE OF CONTENTS

1. **INTRODUCTION:** Narrative that briefly (one paragraph) describes the subject, purpose and scope of the research.

This program will develop a control system that provides amputees outfitted with high-channel-count myoelectric signal monitoring systems, simultaneous use of multiple degrees of freedom (DOF) of a prosthetic limb. The program will also develop software and hardware tools prosthetists can use to adjust controller behavior to maximize limb function for each patient. The main strength of this program is that it combines basic research with existing, proven technology to provide novel rehabilitation strategies that meet a critical need in the military and civilian upper-limb amputee population.

2. **KEYWORDS:** Provide a brief list of keywords (limit to 20 words).

High-channel count myoelectric control of multi-articulating prosthetic limbs
Prosthetist tool development for improved fitting and tuning of limbs

3. **ACCOMPLISHMENTS:** The PI is reminded that the recipient organization is required to obtain prior written approval from the awarding agency grants official whenever there are significant changes in the project or its direction.

What were the major goals of the project?
List the major goals of the project as stated in the approved SOW. If the application listed milestones/target dates for important activities or phases of the project, identify these dates and show actual completion dates or the percentage of completion.

The Statement of Work is as follows. Completion dates / percentage of completion is shown in bold and italics.

1. In Specific Aim 1 we will develop strategies for control of a prosthesis comprising a two degree-of-freedom wrist (pronation/supination and flexion/extension) and single degree-of-freedom hand (finger flexion/extension) based on input from multiple surface EMG sites. We will acquire EMG data from subjects using surface electrodes, implement control strategies on a Neural Interface System to control a virtual limb, and evaluate various control strategies with the goal of determining the suitability of each to clinical deployment. These strategies will be evaluated with unilateral transradial amputees.
1.1 Software development of control strategies for a virtual limb will **occur over the first 18 months of the project.** This will be an iterative process, taking account of feedback from initial clinical usage.

100% complete. We have completed the software development for controlling the virtual limb.

1.2 IRB submissions will be made for one clinical site **by the end of month 3**. IRB approval for this non-significant risk study is expected by the end of month 6.

100% complete. The study protocol has been approved by both the IRB and the Human Research Protection Office (HRPO).

1.3 By the end of month 12, we will provide the first clinical demonstration of control of a three-DoF virtual limb using surface-acquired EMG on a unilateral amputee.

100% complete. The first clinical subject has used surface EMG to control three DoFs of the virtual limb.

1.4 By the end of month 21, we will provide clinical demonstration of control of a three-DoF virtual limb using surface-acquired EMG.

100% complete. All three subjects for this task have been enrolled and completed the phase I protocol for controlling the virtual limb with surface EMG.

2. In Specific Aim 2 we will advance the control strategy development of Specific Aim 1 by driving a commercially available two DoF wrist and single DoF hand. The high-level control system will provide analog signals with the appropriate features of EMG for presentation to the individual controllers of a bench-mounted prosthesis.

2.1 Software development supporting a system of emulated EMG signals supplying the controllers of a commercial prosthesis will occur from the beginning of month 19 through the end of month 33. Software development will occur iteratively with feedback from clinical testing.

100% complete. We can fully integrate with the controls of a commercial prosthesis using emulated EMG output.

2.2 Clinical evaluation of multi-DoF control of a commercial prosthesis will begin at the clinical site during month 25. We will provide results of clinical study by the end of month 36.

20% complete. We have received a custom prosthesis with a 2 DOF wrist from BeBionic, and we have started system integration.

3. In Specific Aim 3 we will translate the functionality of the bench-top system developed in Specific Aim 2 into a portable system which demonstrates the utility of the control strategy in ambulatory subjects. We will implement recent training hardware-based methodologies such as Prosthesis Guided Training and test their efficacy.

3.1 Software development for the portable system will occur from month 31 through 42. Software development will occur iteratively with feedback from clinical sites.

60% complete. We are near completion of the software interface for training the Kalman filter and will soon begin system integration.

3.2 Clinical evaluation of multi-DoF control of a commercial prosthesis using a portable controller will begin at the clinical site during month 37. We will provide results of clinical study by the end of month 48.

What was accomplished under these goals?
For this reporting period describe: 1) major activities; 2) specific objectives; 3) significant results or key outcomes, including major findings, developments, or conclusions (both positive and negative); and/or 4) other achievements. Include a discussion of stated goals not met. Description shall include pertinent data and graphs in sufficient detail to explain any significant results achieved. A succinct description of the methodology used shall be provided. As the project progresses to completion, the emphasis in reporting in this section should shift from reporting activities to reporting accomplishments.

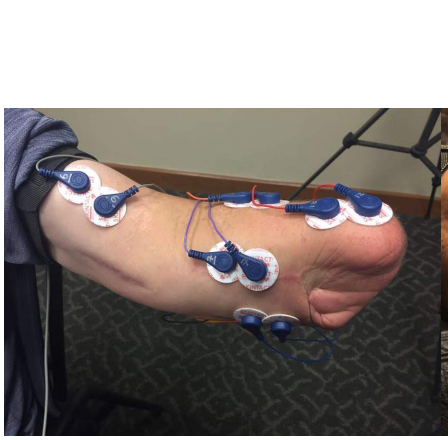
Major Accomplishments:

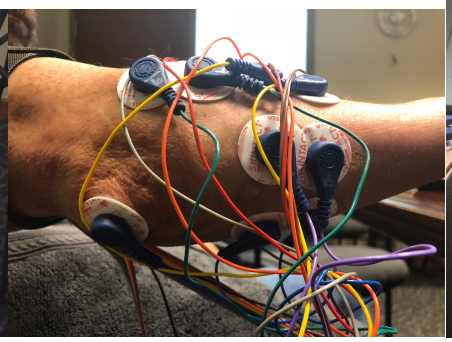
HRPO Approval

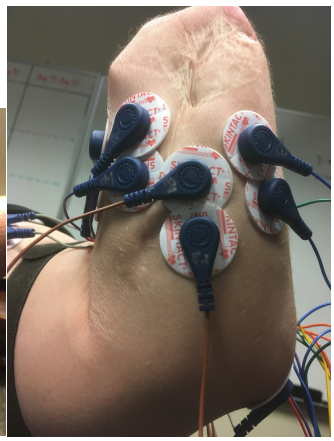
The current protocol has received both IRB and HRPO approval. This marked a major milestone and overcame a major obstacle in study progression by allowing us to move forward with subject recruitment.

Completion of the Aim 1 clinical study

All three upper limb amputee clinical subjects have been enrolled and completed the Aim 1 protocol with the virtual limb. After signing the informed consent, the subject practiced the individual DoF motions to be controlled using the virtual limb while watching a video of each motion. Once the subject was comfortable with the limb movements, the residual limb was outfitted with 8 pairs of differential surface EMGs using targeted placement over selected muscle regions, shown below.

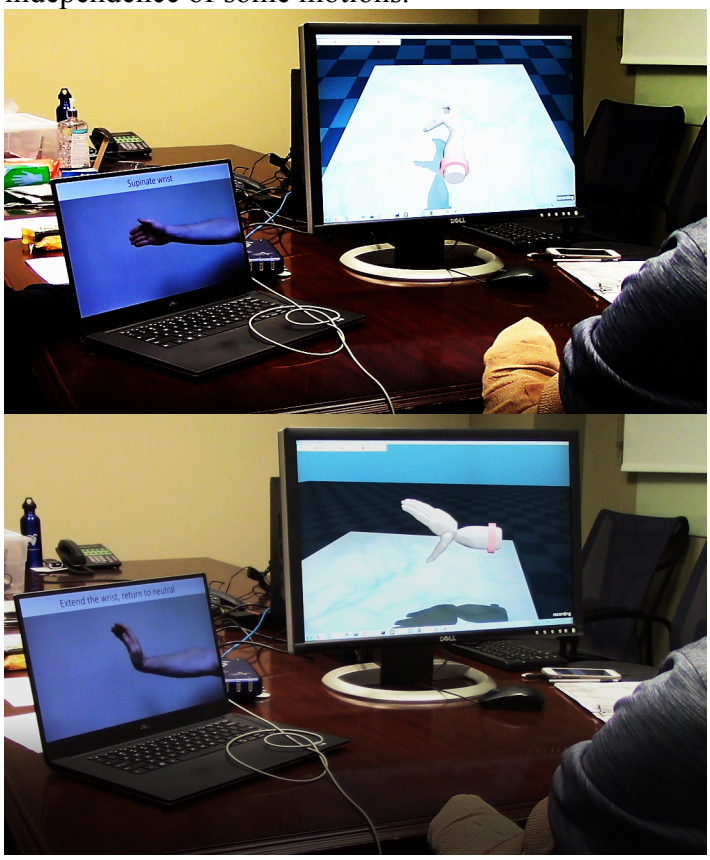

Subject 1


Subject 2


Subject 3

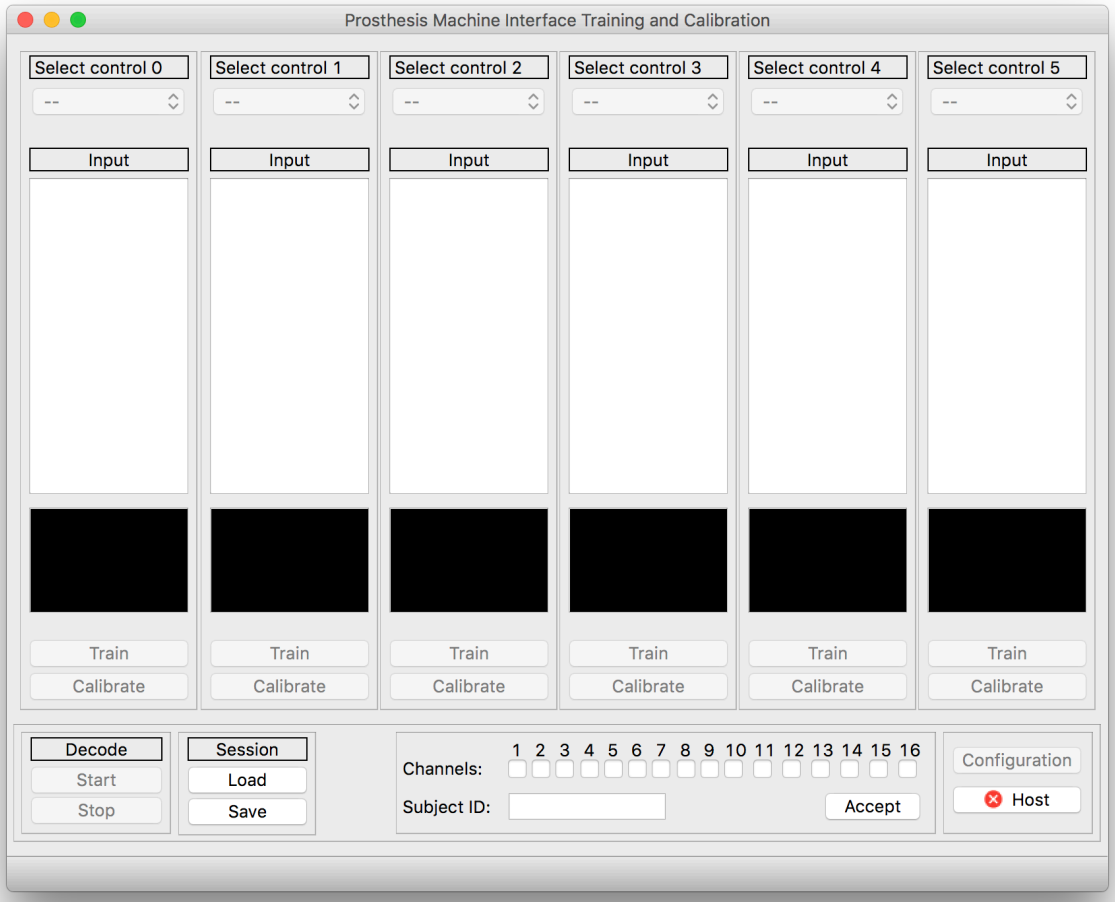
The EMG output was mapped to the selected DoFs of the virtual limb (wrist rotation, wrist flexion/extension, and hand open/close) using a direct control algorithm. Using a video to illustrate, the subject was instructed to recreate selected movements with the virtual limb. The movements were presented in increasing levels of complexity (singe DoF to multiple DoF).

Using surface EMG with direct control, all subjects were able to recreate many of the movements with the virtual limb. Due to the different limb morphologies and muscle sparing of each individual, the combinations of movements achieved by each subject varied. While each subject achieved several single- and multi-DOF, apparent cross-talk from the surface EMGs limited the independence of some motions.



Software Development for Control Algorithm Training

We have selected the Kalman filter for decoding the EMG signal for control of the prosthetic limb. This decode method leverages the input from multiple channels to control the movement of the prosthetic limb. Utilizing the multi-channel input reduces the impact of cross-talk between channels that limits the effectiveness of direct control.
A Kalman filter must be trained to create a control montage for the selected motions. We are developing a user interface for training the filter to be used with the computer-based system in Aim 2 and the portable system in Aim 3. This interface enables training of each degree of freedom and then creates the signal matrix which is then used to control the prosthetic limb. After calibration the user can also manually adjust aspects of the control scheme to fine tune the output to achieve superior prosthetic control. A screen shot of the training and calibration interface is included below.



<u>Code on the Box for portable prosthesis control</u>
To support the portable prosthesis control phase of the project we are developing a system capable of recording and processing EMG signals in real-time that can be worn in a belt-pack configuration. The system includes a 32-channel amplifier module that digitizes and multiplexes EMG signals in a front end mounted on the limb. Signals are digitally transmitted through a cable to the beltpack which houses an Intel processor used to run the Kalman filter decode algorithm. End-to-end processing time to amplify, filter, digitize, multiplex, and process signals is on the order of about 50ms.

What opportunities for training and professional development has the project provided?
If the project was not intended to provide training and professional development opportunities or there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe opportunities for training and professional development provided to anyone who worked on the project or anyone who was involved in the activities supported by the project. "Training" activities are those in which individuals with advanced professional skills and experience assist others in attaining greater proficiency. Training activities may include, for example, courses or

one-on-one work with a mentor. "Professional development" activities result in increased knowledge or skill in one's area of expertise and may include workshops, conferences, seminars, study groups, and individual study. Include participation in conferences, workshops, and seminars not listed under major activities.

Nothing to Report.

How were the results disseminated to communities of interest?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe how the results were disseminated to communities of interest. Include any outreach activities that were undertaken to reach members of communities who are not usually aware of these project activities, for the purpose of enhancing public understanding and increasing interest in learning and careers in science, technology, and the humanities.

Nothing to Report

Describe briefly what you plan to do during the next reporting period to accomplish the goals and objectives.

Our efforts over the next quarter will be directed primarily along two lines: Continued development of decoding algorithm interface and initiation the next round of clinical testing with the prosthetic limb.

Algorithm Interface
We will continue with our work developing the user interface for algorithm training and prosthesis control. Specifically, we must conduct firmware development which enables the training and control algorithm to communicate with the prosthetic limb.

Clinical Testing
Once the interface development is complete we will move forward with the next phase of clinical testing. The subjects from Aim 1 have expressed their willingness to return for the next round of testing. Thus, these subjects will be contacted initially for participation. However, if these subjects are unable to participate, we have additional potential subjects who have expressed interest in participating in this phase of the study.

4. **IMPACT:** Describe distinctive contributions, major accomplishments, innovations, successes, or any change in practice or behavior that has come about as a result of the project relative to:

What was the impact on the development of the principal discipline(s) of the project?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe how findings, results, techniques that were developed or extended, or other products from the project made an impact or are likely to make an impact on the base of knowledge, theory, and research in the principal disciplinary field(s) of the project. Summarize using language that an intelligent lay audience can understand (Scientific American style).

Patients with transradial amputations using the currently available hand prostheses have limited options for intuitive, smooth movements. Although over the last decade, substantial improvements have been made to prosthetic arm technologies, their full utility has yet to be realized by patients in their daily lives because of poor control systems. Here, we offer a step forward in moving to more intuitive, simultaneous multi-DoF movements using higher input channel count prosthetic limbs. We are offering tools to reduce the burden on prosthetists who must adjust settings for mode switching, and tune controller parameters, including gain and threshold, for many more myoelectric channels. Further exacerbating the challenges prosthetists face, are issues associated with electrode placement, and a general lack of familiarity with multi-electrode control strategies and proprietary controllers. Although many academic research groups have demonstrated innovative multi-electrode limb control strategies, most are not easily adapted to existing clinical practice. In the context of the increased complexity associated with novel control technologies and higher channel counts, and given that prosthetists are reimbursed for only a limited number of hours (typically 4) spent tuning a patient's controller, software and hardware tools are needed to facilitate the prosthetist's tasks. For emerging control technologies to be clinically successful, strong immediate development efforts are needed to generate a set of enabling tools and methodologies that are practical and cost-effective in a clinical setting.

What was the impact on other disciplines?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe how the findings, results, or techniques that were developed or improved, or other products from the project made an impact or are likely to make an impact on other disciplines.

In the development of clinically relevant neuroprostheses, there is a profound need for the ability to run complex decodes and provide real-time control of stimulation systems and external peripherals. These experiments often require rack mounted data acquisition systems, external stimulators, and extra computers to develop and run the analyses. The need for this equipment and the difficulty of development limits these experiments to laboratory environment where movement and behavior of the subjects are greatly constrained.

The Ripple Nomad being developed as part of this project offers a portable, programmable platform for neural interface researchers. This is a wireless, battery powered data acquisition and stimulator that supports up to 512 channels plus analog and digital inputs. Additionally, the Nomad can control digital outputs and has CAN bus support, common for control of modern upper limb prosthesis. A Nomad can easily be worn by human or animal subjects undergoing freely moving behaviors. The Ripple Nomad system will enable experimenters to easily transition from a laboratory development environment to one where decode, stimulation, and control routines can be run directly on the Nomad hardware. This will allow for animal subjects behave interact under more naturalistic conditions, and for advanced clinical investigators to test their systems in an ambulatory environment.

What was the impact on technology transfer?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe ways in which the project made an impact, or is likely to make an impact, on commercial technology or public use, including:

- *transfer of results to entities in government or industry;*
- *instances where the research has led to the initiation of a start-up company; or*
- *adoption of new practices.*

Nothing to Report.

What was the impact on society beyond science and technology?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe how results from the project made an impact, or are likely to make an impact, beyond the bounds of science, engineering, and the academic world on areas such as:

- *improving public knowledge, attitudes, skills, and abilities;*
- *changing behavior, practices, decision making, policies (including regulatory policies), or social actions; or*
- *improving social, economic, civic, or environmental conditions.*

There are approximately 18,500 annualized upper limb amputations in the United States within the military and civilian communities. Acquired amputation of the upper limb is more often due to trauma, rather than dyvascular disease, are typically relatively young, active and productive in their careers and communities.

The personal goals of our wounded warriors in many ways follow that of wounded civilians: community reintegration, social acceptance, and the ability to be productive and excel at vocational goals. In addition to these aspects of reintegration into civilian life, many service personnel choose to return to duty after amputation. In 1995, 2.3% of amputee service personnel chose Return to Duty. By 2009, this number increased to an astounding 20%. About 21% of amputees from OIF/OEF are upper limb, and 80% of these use a prosthesis. The number of persons living with UL amputation continues to increase each year. With appropriate medical and rehabilitation intervention, this relatively young, patient population has the potential to return to long and productive lives after amputation.

Upon completion of this project, our wounded warriors can be provided the systems they so deserve to enable a full life, community reintegration, social acceptance, and the ability to be productive, and to partially mitigate a horrendous emotional experience. We expect that the natural and intuitive limb function facilitated by this effort will be an aid to mental and emotional wellbeing. These goals apply equally to both reintegration into civilian life and return to duty.

5. **CHANGES/PROBLEMS:** The PD/PI is reminded that the recipient organization is required to obtain prior written approval from the awarding agency grants official whenever there are significant changes in the project or its direction. If not previously reported in writing, provide the following additional information or state, "Nothing to Report," if applicable:

Nothing to Report.

Actual or anticipated problems or delays and actions or plans to resolve them
Describe problems or delays encountered during the reporting period and actions or plans to resolve them.

Nothing to report

Changes that had a significant impact on expenditures
Describe changes during the reporting period that may have had a significant impact on expenditures, for example, delays in hiring staff or favorable developments that enable meeting objectives at less cost than anticipated.

Nothing to report

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

Describe significant deviations, unexpected outcomes, or changes in approved protocols for the use or care of human subjects, vertebrate animals, biohazards, and/or select agents during the reporting period. If required, were these changes approved by the applicable institution committee (or equivalent) and reported to the agency? Also specify the applicable Institutional Review Board/Institutional Animal Care and Use Committee approval dates.

Nothing to Report.

Significant changes in use or care of human subjects

Nothing to Report.

Significant changes in use of biohazards and/or select agents

N/A

6. **PRODUCTS:** List any products resulting from the project during the reporting period. If there is nothing to report under a particular item, state "Nothing to Report."

- **Publications, conference papers, and presentations**
  Report only the major publication(s) resulting from the work under this award.

  Journal publications. *List peer-reviewed articles or papers appearing in scientific, technical, or professional journals. Identify for each publication: Author(s); title; journal; volume: year; page numbers; status of publication (published; accepted, awaiting publication; submitted, under review; other); acknowledgement of federal support (yes/no).*

Nothing to Report.

  Books or other non-periodical, one-time publications. *Report any book, monograph, dissertation, abstract, or the like published as or in a separate publication, rather than a periodical or series. Include any significant publication in the proceedings of a one-time conference or in the report of a one-time study, commission, or the like. Identify for each one-time publication: author(s); title; editor; title of collection, if applicable; bibliographic information; year; type of publication (e.g., book, thesis or dissertation); status of publication (published; accepted, awaiting publication; submitted, under review; other); acknowledgement of federal support (yes/no).*

Nothing to Report.

  Other publications, conference papers and presentations. *Identify any other publications, conference papers and/or presentations not reported above. Specify the status of the publication as noted above. List presentations made during the last year (international, national, local societies, military meetings, etc.). Use an asterisk (*) if presentation produced a manuscript.*

Nothing Additional to Report.

List the URL for any Internet site(s) that disseminates the results of the research activities. A short description of each site should be provided. It is not necessary to include the publications already specified above in this section.

Nothing to Report.

Technologies or techniques

Identify technologies or techniques that resulted from the research activities. Describe the technologies or techniques were shared.

Kalman Filter Training and Prosthesis Control Interface

The user interface developed for this project will provide a user-friendly system for the training and control of an advanced myoprosthesis using high-channel count EMG input. This user interface will allow researchers and clinicians an accessible means to leverage a complex control system for multiple DOF prosthesis control.

- **Inventions, patent applications, and/or licenses**
  Identify inventions, patent applications with date, and/or licenses that have resulted from the research. Submission of this information as part of an interim research performance progress report is not a substitute for any other invention reporting required under the terms and conditions of an award.

Nothing to Report.

- **Other Products**
  Identify any other reportable outcomes that were developed under this project. Reportable outcomes are defined as a research result that is or relates to a product, scientific advance, or research tool that makes a meaningful contribution toward the understanding, prevention, diagnosis, prognosis, treatment and /or rehabilitation of a disease, injury or condition, or to improve the quality of life. Examples include:
  - *data or databases;*
  - *physical collections;*
  - *audio or video products;*
  - *software;*
  - *models;*
  - *educational aids or curricula;*
  - *instruments or equipment;*
  - *research material (e.g., Germplasm; cell lines, DNA probes, animal models);*
  - *clinical interventions;*
  - *new business creation; and*
  - *other.*

Nothing to Report.

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?
Provide the following information for: (1) PDs/PIs; and (2) each person who has worked at least one person month per year on the project during the reporting period, regardless of the source of

compensation (a person month equals approximately 160 hours of effort). If information is unchanged from a previous submission, provide the name only and indicate "no change".

Name: Elliott Barcikowski
Project Role: Senior Software Engineer
Nearest person-months worked: 6.1
Contribution to Project: Validation of the virtual limb environment

Name: Will Talmadge
Project Role: Senior Software Engineer
Nearest person-months worked: 5.2
Contribution to Project: Bench testing of the portable system

Name: Scott Hiatt
Project Role: Senior Software Engineer
Nearest person-months worked: 1.2
Contribution to Project: Support of the portable system

Name: Daniel McDonnall
Project Role: Principal Investigator
Nearest person-months worked: 2.7
Contribution to Project: Project Management

Name: Charla Howard
Project Role: Research Scientist
Nearest person-months worked: 0.6
Contribution to Project: Clinical trial design and data collection

Name: Isaac Myers
Project Role: Systems Engineer
Nearest person-months worked: 2.0
Contribution to Project: Design of decode algorithm and interface for portable system

Name: Andrew Wilder
Project Role: Senior Software Engineer
Nearest person-months worked: 1.8
Contribution to Project: Support for decode algorithm and interface development

Name: Robert Roundy
Project Role: Senior Software Engineer
Nearest person-months worked: 2.5
Contribution to Project: Development of tools for embedded algorithms on the data acquisition system

Name:	Steve Barrus
Project Role:	Senior Electrical Engineer
Nearest person-months worked:	0.6
Contribution to Project:	Development and integration of prosthesis control

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

If the active support has changed for the PD/PI(s) or senior/key personnel, then describe what the change has been. Changes may occur, for example, if a previously active grant has closed and/or if a previously pending grant is now active. Annotate this information so it is clear what has changed from the previous submission. Submission of other support information is not necessary for pending changes or for changes in the level of effort for active support reported previously. The awarding agency may require prior written approval if a change in active other support significantly impacts the effort on the project that is the subject of the project report.

Nothing to Report.

What other organizations were involved as partners?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe partner organizations – academic institutions, other nonprofits, industrial or commercial firms, state or local governments, schools or school systems, or other organizations (foreign or domestic) – that were involved with the project. Partner organizations may have provided financial or in-kind support, supplied facilities or equipment, collaborated in the research, exchanged personnel, or otherwise contributed.

Provide the following information for each partnership:
Organization Name:
Location of Organization: (if foreign location list country)
Partner's contribution to the project (identify one or more)

- *Financial support;*

- *In-kind support (e.g., partner makes software, computers, equipment, etc., available to project staff);*
- *Facilities (e.g., project staff use the partner's facilities for project activities);*
- *Collaboration (e.g., partner's staff work with project staff on the project);*
- *Personnel exchanges (e.g., project staff and/or partner's staff use each other's facilities, work at each other's site); and*
- *Other.*

Nothing to report

8. SPECIAL REPORTING REQUIREMENTS

COLLABORATIVE AWARDS: For collaborative awards, independent reports are required from BOTH the Initiating Principal Investigator (PI) and the Collaborating/Partnering PI. A duplicative report is acceptable; however, tasks shall be clearly marked with the responsible PI and research site. A report shall be submitted to **https://ers.amedd.army.mil** for each unique award.

QUAD CHARTS: If applicable, the Quad Chart (available on https://www.usamraa.army.mil) should be updated and submitted with attachments.

9. APPENDICES: Attach all appendices that contain information that supplements, clarifies or supports the text. Examples include original copies of journal articles, reprints of manuscripts and abstracts, a curriculum vitae, patent applications, study questionnaires, and surveys, etc.

Workflow Optimization for Tuning Prostheses with High Input Channel Count

W81XWH-16-0767

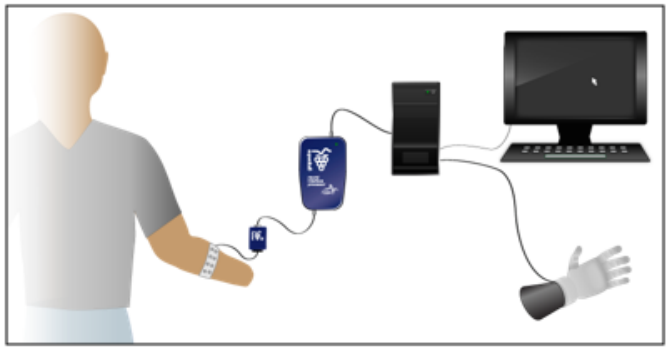
PI: Daniel McDonnall **Org:** Ripple LLC **Award Amount:** $1,288,666

Study/Product Aim(s)

- Aim 1: Develop multichannel myoprosthetic control algorithm
- Aim 2: Test system with transradial subjects on benchtop system
- Aim 3: Validate approach with portable control system

Approach

Ripple is developing an improved myoelectric system for more dexterous upper limb prosthesis control. The approach will utilize a multichannel EMG recording system and a portable data processing unit. In this project, we will develop the control software and validate in a clinical study with transradial amputee subjects.



Accomplishment: Completion of clinical testing with the virtual limb, development of the user interface GUI for benchtop and portable system calibration

Timeline and Cost

Activities CY	17	18	19	20
Control virtual limb				
Control benchtop system				
Control portable system				
Estimated Budget ($K)	**$510**	**$300**	**$300**	**$179**

Updated: October 2018

Goals/Milestones

CY17 Goal

☑ Regulatory submission
☑ Start clinical demo of control of virtual limb

CY18 Goals

☑ Validate software for virtual limb control
☑ Complete clinical testing of virtual limb

CY19 Goal – Production readiness

☐ Software for benchtop control system complete
☐ Clinical testing of benchtop system

CY20 Goal – Navy suitability testing

☐ Software for portable control system
☐ Clinical testing of portable system

Budget Expenditure to Date

Projected Expenditure through 2018: $810k
Actual Expenditure: $707k