AWARD NUMBER: W81XWH-17-1-0031

TITLE: User-Independent Intent Recognition on a Powered Transfermoral Prosthesis

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REPORT DATE: February 2018

TYPE OF REPORT: Annual

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

DISTRIBUTION STATEMENT: Approved for Public Release; Distribution Unlimited

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE February 2018	**2. REPORT TYPE** Annual	**3. DATES COVERED** 15 Jan 2017 - 14 Jan 2018

4. TITLE AND SUBTITLE
User-Independent Intent Recognition on a Powered Transfermoral Prosthesis

5a. CONTRACT NUMBER

5b. GRANT NUMBER
W81XWH-17-1-0031

5c. PROGRAM ELEMENT NUMBER

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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

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

U.S. Army Medical Research and Materiel Command

Fort Detrick, Maryland 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This research will develop intuitive and smart intent recognition systems for powered prostheses to predict user intent to optimally supply power to the gait cycle during locomotion tasks. Intelligent intent recognition systems are needed for these prostheses to be clinically deployable. The primary scope of this project first involves developing and preparing a powered prosthesis complete with control technologies for clinical testing with patients with transfemoral amputation. We will collect data during walking which includes various speeds, stairs and ramps. We will compare the clinical effectiveness of different intent recognition systems on lower limb amputees using a powered prosthesis. This research will result in clinically meaningful parameters including the success rate, speed and energetic cost of the amputees performing a circuit of locomotion activities including level walking, stairs and ramps. Biomechanics of movement and energetic cost using the controllers will be quantified and compared to passive prosthesis ambulation. Results to date include the development of the mechanical, electrical, and control systems for the powered prosthesis. This includes full embedded programming such that all computing is local to the device. We have performed initial able-bodied testing and began testing in patient populations and prepared initial preliminary data. Results show that biological (human) biomechanics can be achieved on the powered prosthesis test system using our controllers.

15. SUBJECT TERMS: Powered knee/ankle prostheses, amputation, intent recognition, biomechanical outcomes, prosthetic control systems, pattern recognition

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** USAMRMC
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	Unclassified	22	**19b. TELEPHONE NUMBER** *(include area code)*

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1. INTRODUCTION:

Powered prostheses are a promising new technology that may help lower limb amputees to function at higher levels in their daily lives. These individuals suffer from significantly impaired mobility including expending up to 60% more energy than non-amputee individuals. Less than 25% of transfemoral amputees older than 50 achieve community mobility on passive prostheses. Research and industry teams have begun building powered prostheses that include motors to actively assist amputees to walk and perform various tasks encountered in everyday situations such as stepping up a stair, standing up, and traversing difficult and uneven terrain such as slopes and ramps. An important objective is for the computer on the prosthesis to understand what the amputee wants to do. By accurately decoding the amputee’s intentions, the computer can appropriately coordinate the assistance of the powered prosthesis to the amputee’s needs. A powerful technique to understand the amputee’s intentions is to use pattern recognition, which is a technology that is commonly used in speech recognition, image analysis and medical diagnostics. Pattern recognition is capable of automatically determining the amputee’s intent and can allow amputees to easily and intuitively use their powered prostheses in their everyday lives. However, if the pattern recognition software incorrectly estimates the user intent, then the powered prosthesis may not be as helpful or may even get in the way of an amputee’s intended movements. Additionally, pattern recognition requires training data that must be collected from the amputee before using it. We have developed new pattern recognition systems that are more accurate and do not necessarily require training data directly from the amputee. The proposed research will develop and test these pattern recognition systems with amputees using a state-of-the-art powered prosthesis. The research will determine the benefit of pattern recognition intent recognition systems by measuring key clinical parameters such as how quickly amputees are able to move with the powered prosthesis and their energetic cost of doing so. The end result of this research will be intent recognition systems capable of implementation on computers embedded on powered prostheses. This will be useful to lower limb amputees who use powered prostheses in the future as intent recognition systems can help amputees achieve a greater level of independence and mobility.

2. KEYWORDS:

Provide a brief list of keywords (limit to 20 words).

Powered knee/ankle prostheses, amputation, intent recognition, biomechanical outcomes, prosthetic control systems, pattern recognition

3. ACCOMPLISHMENTS:

What were the major goals of the project?

***Specific Aims 1:* Compare intent recognition accuracy of the user-independent system to the user-dependent system in real-time as amputees ambulate over different locomotion modes.**

Major Task 1: Subject Recruitment and Fitting
- Milestone of HRPO and IRB approval at 3 months – 100% completion (on time)

Major Task 2: Prepare prosthetic leg for amputee testing
- Milestone of fully functional system ready for patient testing at 9 months – 100% complete (on time)

Major Task 3: Amputee training and initial data collection for pattern recognition systems
- Milestone of a full set of data from each subject collected at 18 months – 20% complete

Major Task 4: System Implementation
- Milestone of user-dependent and user-independent intent recognition systems ready for deployment – 0% complete

***Specific Aim 2:* Quantify the metabolic cost of walking, amputee biomechanics of motion and completion time and compare between user-dependent and user-independent intent recognition**

Major Task 5: Comparison of user-dependent and user-independent systems during a real-time experiment
- Milestone – experimental comparison between clinical effectiveness of different intent recognition controllers on amputees – 0% complete

***Specific Aim 3:* Compare clinical outcome measures of powered prosthesis ambulation with active intent recognition to passive prosthesis ambulation.**

Major Task 6: Comparison of clinical parameters of powered prosthesis compared to passive prosthesis
- Milestone – experimental comparison of clinical effectiveness of powered prosthesis compared to passive prosthesis – 0% complete

What was accomplished under these goals?

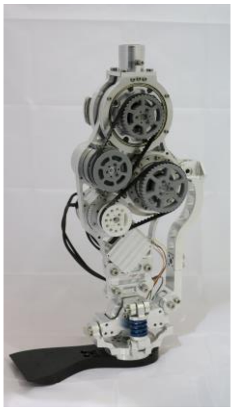
Quarter 1 Activities and Accomplishments:

Major Task 1: Subject Recruitment and Fitting

We successfully got both IRB and HRPO approval for the amputee human subject protocol proposed in this SOW (completion of first milestone). Dr. Lee Childers (certified prosthetist and faculty of Georgia Tech's Prosthetics and Orthotics program) identified multiple transfemoral amputees that would fit our study. One specific subject was contacted. He agreed and is willing to be the first participant. Our first experiments will start with this subject.

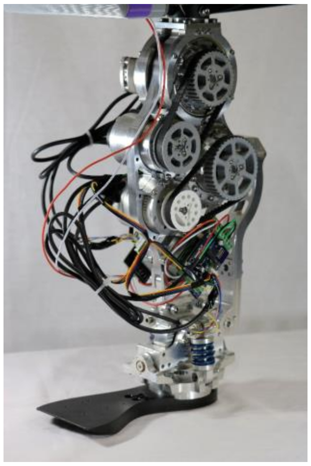
Major Task 2: Prepare prosthetic leg for amputee testing

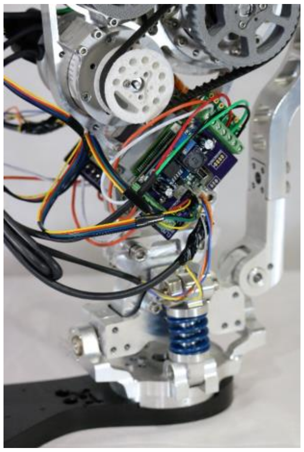
This is where the team's primary effort was for quarter 1. Due to the departure of Aaron Ames, we had to build a copy of the leg prosthesis. In the fall, we modified the design of the AMPRO powered prosthesis to accommodate a much wider variety of amputees (the original device was too tall, based on preliminary testing last summer). We also went ahead and ordered much of the prosthetic leg parts in the fall. My team focused on machining all the custom parts for the leg prosthesis and assembling the device. The device was assembled at the end of the quarter. We began working on the electronics including a number of PCB layouts and integration of the control with our microcontrollers. In collaboration with our prosthetist (Lee Childers), we put together an order for a number of prosthetic device connector components to be able to fit our device to a wide variety of amputee sockets and now have them in lab to test with our device. We also modified a socket device to create a bypass walker/socket for the able-bodied subjects to walk on the powered prosthesis. We have also began to form an initial experimental protocol for testing the leg and controllers on able-bodied subjects. The biggest accomplishment of the first quarter was successfully machining and assembling the prosthetic device, an image of each side of the finalized device is shown below:

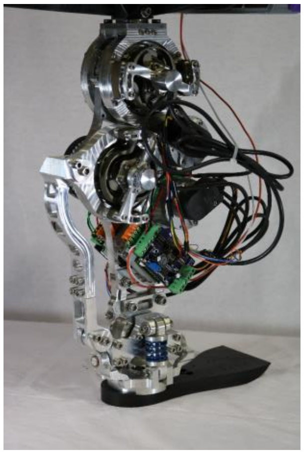


Quarter 2 Activities and Accomplishments:

Major Task 2: Prepare prosthetic leg for amputee testing
In April, designing and manufacturing an electronics box was completed to place the microcontroller, safety stop, and other electrical components needed for the device. In addition, manufacturing of extra parts for the prosthetic device was completed and assembly of adding an able-bodied walking adapter was constructed with an iWALK 2.0 device. This assembly allows an able bodied subject to don the device for safety testing. In May, benchtop testing of all sensors (absolute encoders, incremental encoders, inertial measurement units and force sensitive resistors) and motion controllers were performed to make sure all of the components would be integrated with the device smoothly and efficiently. Custom printed circuit boards were created to help reduce the amount of wiring needed for the device. In June, the team began working on a controls architecture with our Beaglebone black microcontroller and ROS (Robot Operating System) to allow for easier communication and integration for running the prosthetic device. We began development of a graphical user interface designed to allow for easier access to data as well as modifying any state machine control parameters during patient testing. Our team also worked hard on finding a suitable load cell option for the device, as the one we used a year ago failed during testing. A 6-axis load cell from Sunrise Instruments was selected to measure the forces and torques in the prosthetic device. New pictures of the prosthetic leg detailing the newly added electronics platforms by the end of Quarter 2 are shown below:



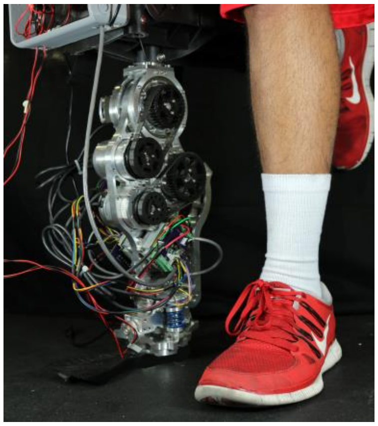


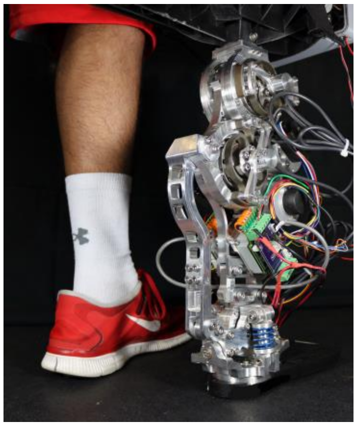


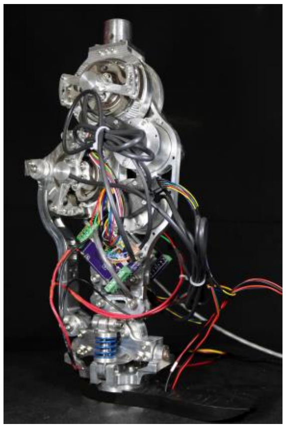
Quarter 3 Activities and Accomplishments:

Major Task 2: Prepare prosthetic leg for amputee testing

During Quarter 3, our team has been developing the controls framework for running the device as well as developing/coding communication protocols with the hardware/sensors used on the device. In July, we focused on implementing a finite state machine for the different modes in level-ground walking. We implemented tuning parameters and equations to allow for smoother walking patterns and began both bench top and able bodied testing to ensure they were correct. We identified issues in terms of communication and real-time control speed. In August, we spent time to change our system over from a BeagleBone processor to a Raspberry Pi processor in order to change the communications from RS232 communication to CANBUS. With RS232 we were limited to 50Hz which we did not deem to be acceptable for real-time control of the powered prosthesis. With the new CAN bus architecture on the Raspberry PI, we now can run at speeds well over 100 Hz (even up to 250-300 Hz) which provides adequate control capability for the powered prosthesis. In September, CANBUS communication with the ELMO motion controllers were finalized to ensure there would be a relatively fast rate for running the low and mid-level of the controls for proper functionality of the device. In both August and September, the team was also testing the stiffness profiles for the torsional springs used in the device to allow for closed loop torque control feedback. In future months, the springs will be modified to allow for higher resolution of torque feedback. An updated version of the leg with an able bodied subject standing on it by the end of Quarter 3 is shown below:







Quarter 4 Activities and Accomplishments:

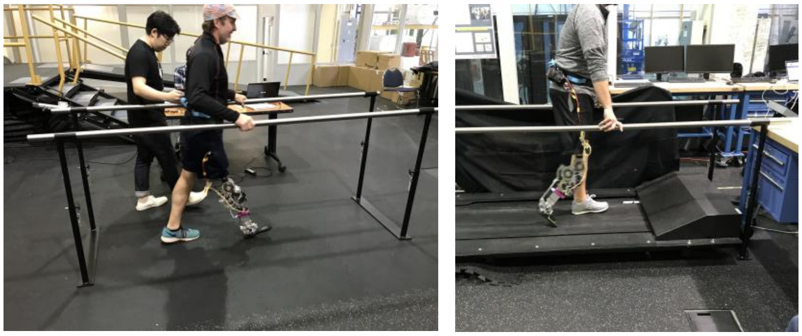
Major Task 2: Prepare prosthetic leg for amputee testing

In October, we focused on implementing the 6 DOF load cell into the prosthetic device which allowed us to have smoother transitions in walking modes for our finite state machine. In the months of November and December, the team also finalized a GUI which allowed for easy data visualization and collection of experimental data. Also in November and December, there were some significant mechanical improvements to the device which included creating variable height adjustment parts so that the device would be able to accommodate people with different leg heights. We were also able to come up with a design to include all electronics except for the batteries to the lower section of the leg compared to the electronics box on top of the able-bodied walking adapter or the socket. We also plan to move the battery down but need to create a custom holder for it on the leg which we plan to design and integrate next quarter.***We met the goal to have the prosthetic leg ready for patient testing at the 9 month mark. We successfully had our first patient experiment with a person with a transfemoral amputation walk on the prosthetic*** leg in November. Dr. Lee Childers helped our team perform fittings and alignments on 4 transfemoral patients in December. After our first experiment, there were a number of issues that needed to be worked out that our team made immediate progress on. For example, our foot needed to be redesigned to provide a better moment arm behind the ankle joint for controlling ankle plantarflexion. We designed and created a new foot for the leg for experiments in December. In addition, it was clear that having many of electronics on the socket was a poor design. We were able to redesign and place everything on the device itself without relying on any instrumentation on the socket which allowed for much more robust experimental testing. The control system to date has focused on level ground walking and tuning parameters both overeground and on a treadmill including at a wide variety of speeds. We still have ongoing work in expanding the controls framework for different ambulation modes (stairs and ramps) which we began this quarter and will be ongoing into Q1 of Year 2.

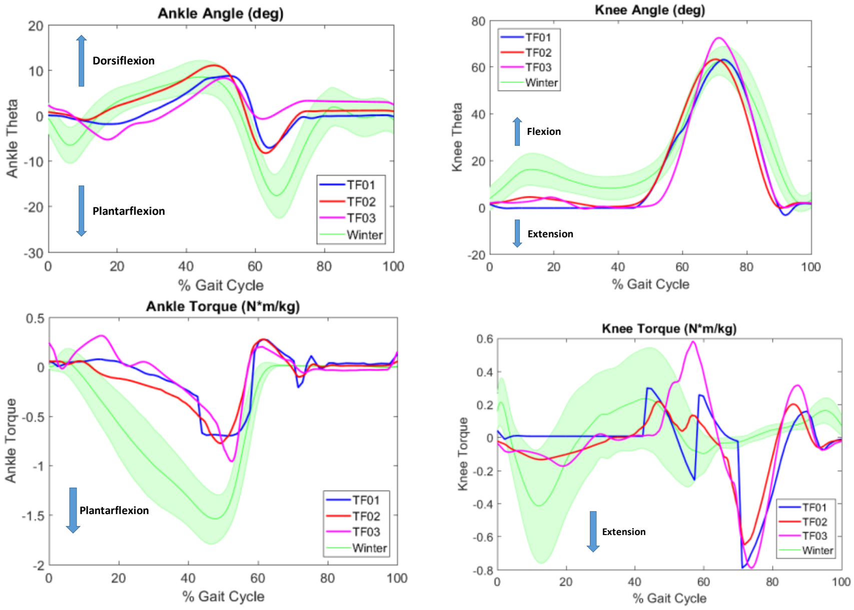
Major Task 3: Amputee training and initial data collection for pattern recognition systems

We have successfully fit and aligned four patients with transfemoral amputation to our device. This initial cohort of subjects will perform all the preliminary testing of the device and initial results. We have begun collecting data first in parallel bars walking over level ground and then also on the treadmill. We performed an initial set of two experiments with one subject to tune parameters and train the subject with the device. This particular subject was the first experimental subject and successfully was able to walk in the parallel bars by the end of the second session. We also performed walking experiments with two additional subjects (one session each). Our team was more experienced and we were able to tune the device and train both subjects to successfully walk in the parallel bars. We also transitioned with both subjects to the treadmill and successfully collected data walking at multiple speeds on the treadmill and further trained and adjusted the device with treadmill walking. This was a large accomplishment for the team as we now have successfully tuned walking parameters and trained three patients with amputation to use our powered prosthesis and have gotten great feedback. The patients are highly impressed with the device and are very excited to continue to work with us on the project and we have already scheduled new experiments for the first quarter of the second year with them. Summary pictures showing our work with patients is shown below.

Fitting and alignments of device to patients. Biological knee joint center was measured on the intact side and the build height of the powered device was modified to allow for alignment of the rotation of the knee joint. Fittings and alignments have been performed on 4 individuals with transfemoral amputation to date.



Individuals with transfemoral amputation walking on the powered knee ankle prosthesis. Patients have walked on the powered device both overground in the parallel bars and on a treadmill at multiple different speeds ranging from slow to fast walking. The experimental team tuned the device control parameters to the subject, provided training for using the device, and collected data. Four walking experiments have been conducted to date on three different patients with amputation.



Walking data from three transfemoral amputees. Powered prosthesis kinematics and kinetics are compared to able-bodied data from the literature (Winter's biomechanics data sets). The top left graph shows angle comparisons, the top right graph shows knee angle comparisons, the bottom left graph shows ankle torque commanded by the prosthesis for each of the three amputees compared to able-bodied net ankle torques, and the bottom right graph shows the knee torque commanded by the prosthesis compared to able-bodied net knee torque.

Results and Discussion:

We have achieved stable control that has allowed three individuals with transfemoral amputation to walk on the device. After a tuning/training session (usually about 30-45 minutes per subject), each subject has been able to walk comfortably on the powered knee/ankle prosthesis. The first important result is our phase recognition. We use a state machine that recognizes four states of walking and switches impedance parameters depending on phase. These phases correspond to: 1) Early/mid stance, 2) Late stance (push-off), 3) Swing flexion (early swing), 4) Swing extension (late swing). Stance and swing phase are triggered based on load cell threshold. The mid to late stance transition is based on an ankle angle threshold. Finally, the swing flexion to swing extension state is triggered based on a threshold in knee velocity. Once the device has been tuned and the subject training, the phase detection algorithm has performed at 100% accuracy, which has allowed continuous walking on the treadmill for over 1000 steps without issues.

The next significant achievement has been to achieve a robust set of walking speeds. We have achieved walking speeds from .5 m/s (slow speed walking) on the treadmill to 0.9 m/s. The control has scaled to allow variable walking speed in this range. Two of our subjects walked on the treadmill at multiple speeds within this range and were able to achieve comfortable walking at each speed without the team needing to tune or adjust any parameters. This demonstrated at least subjectively the ability to accommodate multiple speeds with our control strategy.

Next, the graphs shown above demonstrate some of the initial restorative ability of the powered prosthesis. First, at the ankle joint, we are achieving smooth kinematics that resemble those of able-bodied subjects. Additionally, we are providing active push-off torque. This is noticed and felt by the patients with transfemoral amputation as they are not used to this since their current ankles are not motorized. However, each subject has expressed that they appreciate and really enjoy having this push-off capability at the ankle. They have all expressed the desire to have even more of this push-off torque than we are currently providing. We are currently working on a new version of software that allows for scaling impedance parameters which will allow for us to scale the torque all the way to able-bodied levels. This result at the ankle was very exciting and the study team was happy to see how much this was appreciated by all the patients.

At the knee, the kinematics of motion for each subject matched able-bodied kinematics very closely. Noticeably, we did not provide stance phase knee flexion with the knee. This was on purpose as we have previously found that stance phase knee flexion is extremely difficult for individuals with transfemoral amputation to perform and reject control strategies that force them to do so. Thus, we did not provide the controller with stance phase knee flexion capability and instead kept the knee straight and stiff during early to mid-stance. This resulted in the only primary difference in kinematics at the knee compared to able-bodied subjects. In terms of knee kinetics, values were not necessarily physiological. The most notable difference was that our controller needed to provide significant swing extension torque to get the knee out fast enough for subjects to walk forward. In able-bodied dynamics, the hip provides a lot of this energy and helps to swing the knee without significant knee torque required. Due to the socket interface and a change in hip biomechanics with patients with transfemoral amputation, this energy is not transferred effectively and instead we used the powered prosthesis both to flex to provide nice clearance and then quickly extend to prepare the leg for ground contact. Even though these torques were not fully biomimetic, the kinematics and walking motion achieved were excellent and robust for patients with amputation to walk and achieve variable speed walking. Overall, this is a great set of first results which we plan to present at the MHSRS conference in 2018.

What opportunities for training and professional development has the project provided?

Training and Professional Development:
This project provided significant training for a large range of individuals (see project personnel). This included training for 3 primary groups: 1) Graduate students in Mechanical Engineering and Robotics, 2) Professional Graduate students in the Prosthetics and Orthotics program at Georgia Tech, and 3) Undergraduate training for students in Mechanical, electrical, computer, and biomedical engineering as well as computer science. Training programs included a weekly overall project meeting that rotated between 3 topics: 1) Training session led by PI Young on a technical topic, 2) Journal club on related research, 3) Student presentations on work to date and future plans. These meetings helped to train the study team, share results, and learn about updates in the field. Additionally, PI Young met with the project leaders (graduate students) on a weekly basis. These meetings were specifically for project planning and also aiding the graduate students in learning how to perform the studies for the grant. Additional day-to-day training was provided as needed by the PI for the study team. In addition, Dr. Lee Childers provided multiple clinical training sessions for the lab with patient models to help prepare for clinical fitting and introduce patients to the study team. Finally, a joint biweekly meeting with the Sawicki lab was established in the fall, which included significant training in research methodology and has been a valuable added training tool for the team. Also, PI Young established a Vertically Integrated Project (VIP) at Georgia Tech to increase undergraduate participation and training in research. This project was featured as one of the primary sub-teams in the overall VIP team called "Robotic Human Augmentation". Essentially, this program provides structured training both through the program and the PI as a team of undergrads works on a specific project. A team of 6-8 undergraduates will work on this project each semester through this program, which provides communication and scientific skills. This program also helps to provide professional development as the undergrads in the VIP program present at a research seminar session each semester, which they did in October of this last year. The graduate students also had a number of professional development opportunities through presentations of their work to date on the project at internal poster sessions and workshops at Georgia Tech for graduate students.

How were the results disseminated to communities of interest?

We provided significant outreach to K-12 students throughout the year, but especially during Robotic Week in April at Georgia Tech. A large number of school groups toured PI Young's lab and a demo of the prosthetic device was available and really helped increase interest in the field. The powered leg platform is visually attractive and was of great interest to a large number of younger participants. We also provided a number of lab tours upon request of local schools and communities such as the 100 Black Men of Atlanta and the 100 Scholars Robotics Alliance groups during the summer. This project really helped to stimulate interest in the field by showing a real application to directly impact clinical care.

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

1. We plan to finish developing the multiple ambulation modes controllers to allow us to run experiments on our terrain park platform which will include stairs and ramps.
2. We plan to additionally improve our controls framework by allowing the easy implementation of equations for any given impedance parameter with each state of our state machine. Currently, these must be set to constant values, but we will be modifying them to allow for equations to give us greater flexibility in control
3. We plan to continue patient experiments to advance our training and data collection protocols for the grant activities.

4. We have continued modifications to improve the leg in the works. This includes building a second foot, increasing our range of sizes we can accommodate, performing weight reduction methods, adding higher resolution absolute encoders and building and integrating new springs to increase torque resolution.

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?

Our project is likely to make an impact in the field by advancing the state-of-the-art in control of powered prosthetic legs for improving clinical outcomes with patients with transfemoral amputation. In particular, we expect smarter algorithms to predict what a patient is trying to do and provide the correct set of directions to a robotic assistive prosthesis to provide adequate support. For example, if a patient is trying to ascend a set of stairs, we are designing a system that anticipates this desire and provides automatic and natural support through a powered prosthesis to help a patient walk, ascend a set of stairs and continue to walk. A key advantage of this technology is being able to provide active power generation at the knee and ankle, which allows us to help a patient similar to what biological muscles do. We hope to fully restore assistive capabilities on the amputated side such that both lower limbs are providing similar amount of overall work. This would help solve a huge issue in the field in that patients with amputation tend to rely on their non-amputated side much more than their prosthesis which leads to asymmetric loading and degeneration of the joints. Our research will help to offload that excess loading by providing smart assistance to the impaired side and ideally lead to better long term clinical outcomes in this patient population.

What was the impact on other disciplines?

The technology that was researched and developed for this powered prosthesis is of great value to other closely related disciplines. A clear example for this is in PI Young’s lab who also work on powered orthoses and robotic exoskeletons. Many of the technologies and techniques that are being developed for this project are being extended by other students to problems in the area of powered orthosis technology. Thus, we forsee the benefits of this study extending beyond powered prostheses and into many wearable robotic systems for human augmentation and assistance of patients with walking disability. For example, we have a project that is already translating some of the technology from this project for a hip exoskeleton, which has an application area in providing assistance for stroke survivors. Thus, we see the technology and other developments of this project extending beyond the amputee patient population and will help in many other kinds of walking disability through translation to wearable robotic systems.

What was the impact on technology transfer?

Nothing to report

What was the impact on society beyond science and technology?

Ultimately, the primary area in which the study is likely to make an impact beyond science and technology is in the area of improving social and economic conditions for persons with amputation. We hope to use this technology to improve mobility outcomes and long-term health outcomes for persons with lower limb amputations. Improving mobility outcomes will likely lead to social improvements through increased community ambulation skills and abilities. Increased community participation increases quality of life and overall health outcomes and is a positive benefit for society. Improving health outcomes will lead to significant economic benefits by reducing the load on the overall health system in treating potentially preventable diseases such as osteoarthritis and osteoporosis that result from asymmetric loading of the lower limbs in patients with amputation, which our technology hopes to address in the future.

5. **CHANGES/PROBLEMS:** The Project Director/Principal Investigator (PD/PI) is reminded that the recipient organization is required to obtain prior written approval from the awarding agency Grants Officer 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:

Changes in approach and reasons for change

No change in overall approach. However, the scope of the project has increased beyond what was originally proposed. Due to Ames' leaving, we were forced to initially build our own powered prosthesis rather than using the one already built by the Ames' group. This did delay research activities somewhat early on and heavily increased the cost of the project. However, we were able to leverage significant internal funds (primarily PI Young's start-up package) to provide the additional funds needed to cover the increased scope of the project.

Actual or anticipated problems or delays and actions or plans to resolve them

We had a delay during Quarter 3 of the year. Once the prosthetic leg was build, there were a number of technical issues that had to be resolved before we would be ready for patient testing. One of the largest was that in benchtop and human subject testing, we found that our original package was capable of running the control loop at 50Hz, but it was clear we needed to run it much faster than this (at least in the 100-200Hz range). We spent most of August trying to figure out a clean method for this, including switching microprocessor platforms to achieve better CAN communication and allow for faster real-time processing on the leg. We fixed this and performed full implementation during September. We believe these technical change will translate into better results but did result in a 2-month delay. We expect some delays in terms of when we will be collecting patient data, but believe the project is still on a nice track and trajectory and we now have a more fully developed powered prosthetic controls system. Since this delay in Quarter 3, we have continued on track with beginning testing and data collection with patients with amputation.

Changes that had a significant impact on expenditures

Nothing to report

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

Significant changes in use or care of human subjects

Nothing to report

Significant changes in use or care of vertebrate animals.

N/A

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.”

Nothing to report

Books or other non-periodical, one-time publications.

Nothing to report

Other publications, conference papers, and presentations.

No conference presentations on this work yet, however, the research has been presented in multiple internal seminars to student audiences on the Georgia Tech campus.

- **Website(s) or other Internet site(s)**

http://www.epic.gatech.edu/

This is the lab website which shows the research project, collaborators, funding source, and researchers on the project as well as relevant pictures and descriptions.

- **Technologies or techniques**

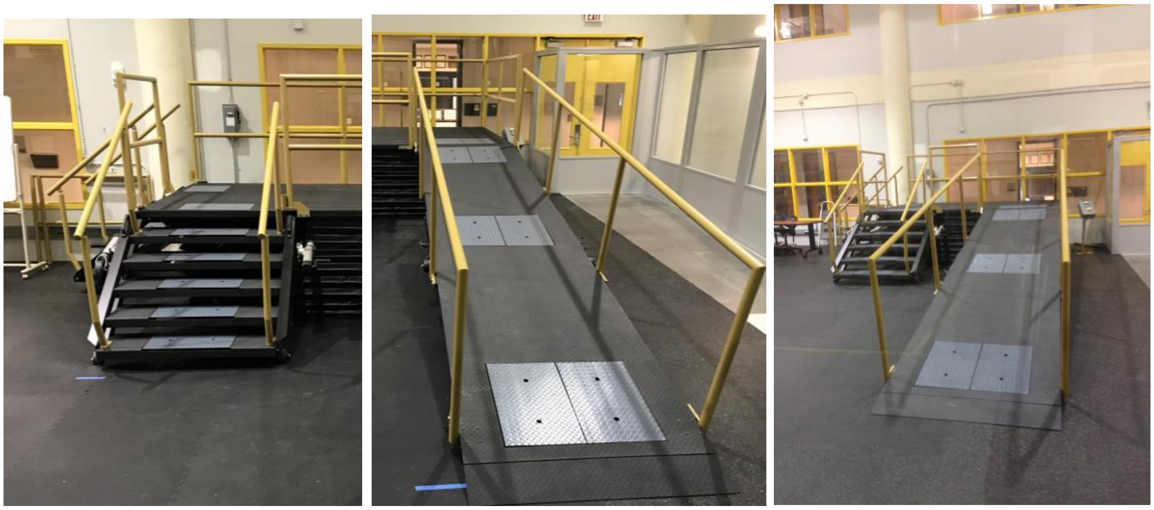
We have developed a new state-of-the-art powered prosthesis. We did this in collaboration with the Ames lab at CalTech. We have improved on their AMPRO 3 design in both mechanics, fitting to amputees, weight reductions, sensing, and control among other things. We plan to disseminate this technology in a planned conference paper to the ASME robotics conference in 2018.

- **Inventions, patent applications, and/or licenses**

Nothing to report

- **Other Products**

Research equipment:
We designed and fabricated a research grade, state-of-the-art terrain park to be used for this project. This is a unique and innovative platform for accessing amputee biomechanics over various terrain. This custom made terrain platform was designed, fabricated, and installed over the first year of the grant and is now fully operational in the lab and is shown in the lab below. Of note, this terrain park has force plate inserts (gray rectangles) to allow for capturing 6-DOF ground reaction forces during walking on the stairs or ramps. Additionally, two sets of stairs were installed, one with an odd number of stairs and one with an even number of stairs. These allow amputees to experience both types of transitions at the top of the steps which further enhances testing capabilities of a powered prosthesis. Motion capture is being installed around this to provide kinematic data in addition to the force plate data. Note that this was paid for out of university funds, however, some of the force plates were budgeted on the grant (4 in total). Additional force plates (6) were purchased which gives 10 in total which allows any section of the terrain park to be fully instrumented (ie either the stairs or ramps) for data collection. Force plates can be easily moved (are all portable) to other sections of the terrain park and the false force plates can be reinserted. This allows for an easily reconfigurable design at any time. One of the most novel parts of this terrain park is that the entire system is on a hydraulic lift. The stairs and the ramp adjust their angle of incline as the top platform moves up and down. We can move the top platform all the way from an ADA ramp (5% incline) to a very steep ramp. Additionally, we can simulate any level of building code stair heights using this piece of equipment. This allows us to test a wide range of terrain parameters when amputees test out the powered leg and simulate real-time conditions while measuring in-depth human biomechanics with force plates and motion capture. This is a custom-made and unique facility that we have created at Georgia Tech to vastly enhance amputee biomechanical tests in real-world environments. Pictures of this terrain park are shown below.



Pictures of the novel terrain park designed for this grant at Georgia Tech in PI Young’s lab.

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Name: *Aaron Young*
Project Role: *PI*
Researcher Identifier:
Nearest person month worked: *4*
Contribution to Project: *Overall responsibility of all aspects of the project. Oversaw all IRB and HRPO approval. Helped with study design and conception. Helped with design and leadership of building the prosthetics leg. Led team in clinical fittings and adjustment of leg controls to patients with transfemoral amputation. Provided training and oversight of study team.*

Name: *Lee Childers*
Project Role: *Senior Personnel*
Researcher Identifier:
Nearest person month worked: *1*
Contribution to Project: *Helped to identify transfemoral amputees to participate in the project. He has also worked with our team to order and obtain prosthetic components to fit our device to the amputee sockets. He has also provided support in identifying a load cell adequate for the device. Finally, he has recruiting a number of individuals with transfemoral amputation, he has fit them to the powered device and provided alignment and clinical support.*

Name: Summer Lee
Project Role: MSPO Student
Researcher Identifier:
Nearest person month worked: 1
Contribution to Project: Helped to fit amputees to the powered prosthesis. She received clinical training from Lee Childers to help support the project. She helped to fabricate a test socket for research and provided fitting and alignment support at patient experiments.

Name: Krishan Bhakta
Project Role: Graduate Student
Researcher Identifier:
Nearest person month worked: 12
Contribution to Project: Lead the effort to fabricate and assemble the prosthetic leg. Has begun to work with Dr. Young on experimental protocol. He has worked significantly with Jonathan (below) on the electronics and controls.

Name: Jonathan Camargo-Leyva
Project Role: Graduate Student
Researcher Identifier:
Nearest person month worked: 11
Contribution to Project: Lead the effort for electronic and PCB componentry to hook up the leg. Has also helped significantly with machining and fabricating the prosthetic leg components. Has been working on coding different models to do the controls and data analysis for the intent recognition aspects of the project.
Funding Support: Fullbright Fellowship

Name: Maegan Tucker
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 3
Contribution to Project: Helped with fabricating, assembling and machining the leg components. Also helped with finding a load cell and fitting in device.
Funding Support: PURA Fellowship

Name: Noel Csomay-Shanklin
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 2
Contribution to Project: Helped with fabricating, assembling and machining the leg components
Funding Support: PURA Fellowship

Name: Will Flanagan
Project Role: Undergraduate Researcher
Nearest person month worked: 2
Contribution to Project: Helped with fabricating, assembling and machining the leg components
Funding Support: PURA fellowship

Name: Lance Lu
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 2
Contribution to Project: Helped with fabricating, assembling and machining the leg components

Name: Achint Lehal
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 2
Contribution to Project: Helped with fabricating, assembling and machining the leg components

Name: Aria Amthor
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 3
Contribution to Project: Working on mechanical improvements and mechatronics

Name: Jared Li
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 3
Contribution to Project: Working on controls and mechatronics with Beaglebone

Name: Sarah Violante
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 1
Contribution to Project: Working on controls and mechatronics with Beaglebone

Name: Vaun Clagett
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 1
Contribution to Project: Working on creating MATLAB GUI

Name: Kevin Edwards
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 2
Contribution to Project: Working on creating MATLAB GUI

Name: Cory Stine
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 1
Contribution to Project: Working on creating MATLAB GUI

Name: Noah Cho
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 1
Contribution to Project: Working on mechanical improvements and redesign of the electronics box

Name: Pratik Kunapuli
Project Role: Undergraduate Researcher
Researcher Identifier:
Nearest person month worked: 1
Contribution to Project: Working on controls framework

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

There is a change in Lee Childer's active support. Lee Childers is the Certified Prosthetist on this grant who is in charge of patient recruitment and fitting of the device. He has moved to run the research arm of labs at the Center for the Intrepid. He will continue to support this grant at the same level of effort as previously described. He has received both approval and orders from the DoD to continue to do so. However, because he is now a DoD employee, he will now be paid directly by the DoD and not by this grant's funds. He will use his portion of the salary to hire out prosthetist support for experiments as necessary as he will no longer be physically present for fittings. However, he will still maintain full clinical advisory roll in terms of recruitment, academy representation, clinical direction, and ensuring proper fitting through a hired prosthetist during the granting period. The PI does not foresee any problems and believe this change will have very little effect on the study overall.

What other organizations were involved as partners?

Organization Name: CalTech
Location of Organization: Pasadena, California
Partner's contribution to the project: Collaboration. Specifically, Dr. Ames, who was originally a collaborator at Georgia Tech left his position here to go to CalTech. He and his group have continued to collaborate on the project, specifically the design of the prosthetic leg throughout the year.

8. SPECIAL REPORTING REQUIREMENTS

COLLABORATIVE AWARDS: N/A

QUAD CHARTS: Attached as a following Appendix

9. APPENDICES: Quad Chart

User-independent Intent Recognition on a Powered Transfemoral Prosthesis

Log Number: OP150063
Award Number: W81XWH-17-1-0031

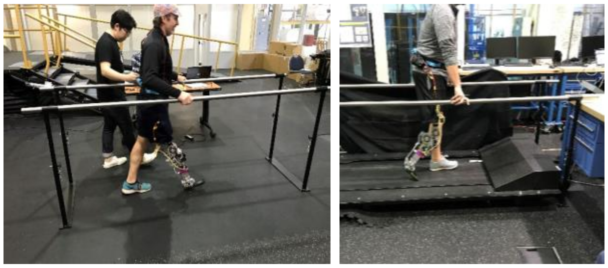
PI: Aaron Young **Org:** Georgia Institute of Technology **Award Amount:** $499,915

Study/Product Aim(s)

- Compare intent recognition accuracy of the user-independent system to the user-dependent system in real-time as amputees ambulate over different locomotion modes
- Quantify the metabolic cost of walking, amputee biomechanics of motion and completion time and compare between user-dependent and user-independent intent recognition.
- Compare clinical outcome measures of powered prosthesis with active intent recognition to passive prosthesis ambulation.

Approach

We will recruit and train 7 transfemoral amputees on a powered knee/ankle prosthesis and collect from this group a set of sensor data as they ambulate over a locomotion circuit including level walking, stairs and ramps. We will implement our intent recognition systems on the powered prosthesis and test them in real-time and measure metabolic cost of walking, completion time, and user biomechanics and compare to passive prosthesis ambulation.



Accomplishment: We have successfully fitted and aligned the powered prosthesis to four individuals with transfemoral amputation. Treadmill and overground walking experiments on three patients have been conducted.

Timeline and Cost

Activities CY	17	18	19	20
Subject Recruitment and Fitting	🟩	🟩		
Training and Data Collection	🟩	🟩		
System Implementation		🟩	🟩	
Real-Time Testing			🟩	🟩
Estimated Budget ($K)	**$195**	**$150**	**$149**	**$5**

Updated: 02/06/2018

Goals/Milestones

CY17 Goal – Subject Recruitment and Fitting
☑ Obtain HRPO and IRB approval
☑ Fully functional system ready for patient testing
CY18 Goals – Initial Data Collection and System Implementation
☐ Collect sensor data from amputees ambulating over terrains
☐ Implement intent recognition systems on the powered prosthesis
CY19 Goal – Real-Time Experimental Testing
☐ Real-time tests of intent recognition systems with amputees using the powered prosthesis
CY20 Goal – Finish all remaining tasks
☐ Analyze data and prepare for publication

Comments/Challenges/Issues/Concerns

- N/A at this time

Budget Expenditure to Date

Projected Expenditure: $500,000
Actual Expenditure: $144,743.53