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TITLE: Determination of Fall Risk for Lower Limb Amputees

PRINCIPAL INVESTIGATOR: Richard R. Neptune

CONTRACTING ORGANIZATION: The University of Texas, Austin, TX

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14. ABSTRACT Falling is a common problem for lower limb amputees, which can lead to reduced physical and emotional health. The overall aims of this project are to: 1) establish a baseline fall detection algorithm derived from simulated falls in a laboratory setting, and 2) utilize and refine the initial laboratory-based algorithm to provide detection of fall events during activities of daily living in real-world environments. To achieve these aims we will perform two human subject experiments. The first experiment will use 30 non-amputee and 5 lower limb amputee individuals to simulate falls in a laboratory setting while wearing the sensor. However, due to the COVID-19 pandemic, we were delayed in starting our data collection. However, in January 2021 we were given approval to start data collection and we have completed 30 non-amputee and 4 lower limb amputee individuals to date. We are currently refining our baseline fall detection algorithm and will begin implementing the algorithm in the sensor the amputees will wear in our second experiment where we will recruit 40 lower limb amputees to wear the sensor in the real-world and we will further refine the algorithm. This will be the focus on Year 2 of the project. An abstract describing our preliminary work was submitted and accepted for presentation at the annual meeting of the American Society of Biomechanics.		

15. SUBJECT TERMS Biomechanics, amputation, balance, fall detection, sensors, algorithms			
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1. Introduction

Falling is a common problem for lower limb amputees, which can lead to reduced physical and emotional health. The overall aims of this project are to: 1) establish a baseline fall detection algorithm derived from simulated falls in a laboratory setting, and 2) utilize and refine the initial laboratory-based algorithm to provide detection of fall events during activities of daily living in real-world environments. The proposed research has two aims: 1) establish a baseline fall detection algorithm derived from simulated falls in a laboratory setting, and 2) utilize and refine the initial laboratory-based algorithm to provide detection of fall events during activities of daily living in pragmatic, real-world environments. To achieve these aims we will perform two human subject experiments. The first experiment will use 30 non-amputee and 5 lower limb amputee individuals to simulate falls in a laboratory setting while wearing the sensor. The sensor will record the motion of the body while falling so that we can create an algorithm to detect a fall in comparison to normal daily activities. The second experiment will recruit 40 lower limb amputees to wear the sensor in the real-world. Amputees will use the sensor for an 8-week period. During that time the sensor will record their motion and detect when a fall occurs. Participants will also report weekly about any fall events that were not detected so that the algorithm can be improved. The outcomes from this two-year project will be new information for clinicians to better understand the number of falls that occur for lower limb amputees. This work represents an initial pilot study to collect data for the fall detection algorithm and lead to future studies where large numbers of amputees will be supplied with the sensors in order to better quantify falling in the larger amputee community and other communities that are at high risk for falling.

2. Keywords

Biomechanics, amputation, balance, fall detection, sensors, algorithms

3. Accomplishments

What were the major goals of the project?

Specific Aim 1: Establish a baseline fall detection algorithm derived from simulated falls in a laboratory setting.	Timeline (months)	Status
Major Task 1.1: Human subject experiment (n=35)	1-7	
Milestone 1.1.1: Obtain approval from the governing Institutional Review Boards.	2	Complete
Milestone 1.1.2: Complete enrollment of all participants and collect experimental data.	5	Near Complete
Major Task 1.2: Analyze Human Subject Data	5-8	
Milestone 1.2.1: Perform machine learning analysis of falling data from healthy subjects to determine the initial fall detection algorithm.	1	Complete
Milestone 1.2.2: Perform hypothesis tests to evaluate the effectiveness of the falling algorithm.	1	Currently in Progress
Milestone 1.2.3: Implement the algorithm in the IMU sensor.	0.5	To Be Done (TBD)
Milestone 1.2.4: Complete writing of manuscript and conference abstract describing initial algorithm development and results.	2	Abstract Submitted, Manuscript in Progress

Specific Aim 2: Utilize and refine the initial laboratory-based algorithm to provide detection of fall events during activities of daily living in pragmatic, real-world environments.	Timeline (months)	
Major Task 2.1: Human subject experiment (n=40)	6-21	
Milestone 2.1.1: Obtain approval from the governing Institutional Review Boards.	2	Complete
Milestone 2.1.2: Complete enrollment of all participants and collect experimental data.	15	TBD
Major Task 2.2: Analyze Human Subject Data	21-24	
Milestone 2.2.1: Perform machine learning analysis on complete dataset to determine final algorithm with all data.	2	TBD
Milestone 2.2.2: Perform hypothesis tests to evaluate the effectiveness of the falling algorithm in the real-world.	3	TBD
Milestone 2.2.3: Complete writing of manuscript and conference abstracts describing the algorithm development, validation and results.	3	TBD

What was accomplished under these goals?

In Year 1, our goal was to establish a baseline fall detection algorithm derived from simulated falls in a laboratory setting. We have completed the data collection for all but one subject and have been developing the fall detection algorithm using machine learning techniques. Using our first 15 non-amputee subjects, we developed an initial algorithm to detect different fall types with an inertial measurement unit (IMU) placed on the individual's shank in preparation for application and validation on individuals with a lower limb amputation. The IMU sensors were placed on both shanks of 15 subjects in positions analogous to the pylon of a prosthesis distal to the knee. Tri-axis accelerometer and gyroscope data were recorded from these devices at 100-Hz while subjects completed an overground course with simulated falls and near-falls. The course was designed to simulate activities of daily living (ADL: walking/running in a straight line at a self-selected pace, navigating turns, sitting and rising from a chair, laying down and getting up from a bed, picking up an object on the floor, and ascending/descending stairs/slopes). Subjects performed 4 types of simulated falls: forward/backward trips (i.e., subjects walked forward/backward until they impacted a fall pad and fell) and left/right lateral falls (i.e., subjects stood with their left/right side adjacent to the fall pad while a lab technician pushed them until they lost balance and fell onto the fall pad). For the simulated near falls, subjects walked until their left/right foot struck the fall pad and then recovered from the stumble.

Raw data were analyzed using the MATLAB Classification Learner Toolbox. First, data were split into two categories: ADL or Fall. Data were divided into 0.5 second windows with a 0.25 second overlap. During these 0.5 second windows, a total of 40 features were computed. Data were randomly split into training (80%) and model verification (20%) sets for each subject and each category. Three different classification algorithms were used for activity classification and validated with 5-fold cross validation: support vector machine with a cubic kernel (SVM), K nearest neighbor with weighted dimensions (kNN), and a bagged decision tree ensemble (Tree). To determine algorithm accuracy, a simple control scheme was created. First, models were implemented on the verification data set. A fall was identified if at least two adjacent windows contained a label associated with a fall. If this occurred within the duration of the fall (~1s), a correct fall classification was made. Falls were labelled by type: forward/backward trips and lateral falls with the sensor placed on the inside/outside leg. Finally, fall detection accuracy was calculated, defined as the number of correct classifications divided by total number of falls.

The results showed forward falls had the lowest detection accuracy for each algorithm. When falling forward, participants can more easily protect their body with their hands and knees, acting to reduce

the acceleration on impact. On average, inside falls had the highest detection accuracy. The inside shank is often the first part of the body that impacts the ground during lateral falls, possibly contributing to the higher accuracy. This is in contrast to previous work that noted highest classification accuracy with backward falls when an IMU sensor is placed on the waist of each participant. This initial study highlighted that fall detection accuracy is not the same across fall types and classification algorithms. An abstract describing our preliminary work was submitted and accepted for presentation at the annual meeting of the American Society of Biomechanics (attached in Appendix). We are currently: 1) seeking to improve the detection of forward falls (e.g., placing sensors in different locations, 2) implementing different classification algorithms such as threshold algorithms and exploring different features), 3) adding the additional data collected to date, and 4) validating these results on individuals with a lower limb amputation.

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

Nothing to Report.

How were the results disseminated to communities of interest?

The preliminary results of our Year 1 activities described above were submitted and accepted for presentation at the annual meeting of the American Society of Biomechanics in August, 2021. The submitted abstract is attached in Appendix.

What do you plan to do during the next reporting period to accomplish the goals?

The focus of Year 2 will be refine our baseline fall detection algorithm and will begin implementing the algorithm in the IMU sensor the amputees will wear. We will then perform a second experiment where we will recruit 40 lower limb amputees to wear the sensor in the real-world and we will further refine the algorithm. We will then complete the writing of a manuscript and conference abstract describing the algorithm development, validation and results.

4. Impact

What was the impact on the development of the principal discipline(s) of the project?

Nothing to Report.

What was the impact on other disciplines?

Nothing to Report.

What was the impact on technology transfer?

Nothing to Report.

What was the impact on society beyond science and technology?

Nothing to Report.

5. Changes/Problems

Nothing to Report.

6. Products

Publications, conference papers, and presentations

Lewallen, L.K., Pew, C.A., Wurdeman, S.R., and Neptune, R.R. (2021). Detection of different fall types in healthy young adults. *45th Annual Meeting of the American Society of Biomechanics*, August 10-13, Atlanta, GA.

Website(s) or other Internet site(s)

Nothing to Report.

Technologies or techniques

Nothing to Report.

Inventions, patent applications, and/or licenses

Nothing to Report.

Other Products

Nothing to Report.

7. Participants & Other Collaborating Organizations

What individuals have worked on the project?

Name:	Richard R. Neptune
Project Role:	PI
Researcher Identifier:	NIH eRA Commons ID: rneptune
Nearest person month worked:	1
Contribution to Project:	Dr. Neptune helped put together the IRB application for approval from both UT Austin and HRPO. He also supervised the graduate student work on the project.
Name:	Lindsey Lewallen
Project Role:	Graduate Student
Researcher Identifier:	N/A
Nearest person month worked:	6
Contribution to Project:	Ms. Lewallen helped put together the two IRB applications and has been working with the machine learning algorithms to be used in the project.

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

Nothing to Report.

What other organizations were involved as partners?

- **Organization Name:** Hanger Clinic
- **Location of Organization:** Austin, TX
 - **Partner's contribution to the project:** Collaboration, help with subject recruitment.
- **Organization Name:** Montana State University,
- **Location of Organization:** Bozeman, MT
 - **Partner's contribution to the project:** Collaboration, help with algorithm development.

8. Special Reporting Requirements

Collaborative Awards: Not applicable

Quad Charts: Attached in Appendix.

9. Appendices

DETECTION OF DIFFERENT FALL TYPES IN HEALTHY YOUNG ADULTS

Lindsey K. Lewallen¹, Corey A. Pew², Shane R. Wurdeman³, and Richard R. Neptune¹

¹Walker Department of Mechanical Engineering, The University of Texas at Austin, Austin, TX

²Department of Mechanical and Industrial Engineering, Montana State University, Bozeman, MT

³Department of Clinical and Scientific Affairs, Hanger Clinic, Austin, TX

email: lindsey.lewallen@utexas.edu

Introduction

Individuals with a lower-limb amputation are at an increased risk of falling compared to young healthy adults. Approximately 50% of individuals with unilateral amputation report at least one fall annually.^{1,2} Falls are dangerous, occasionally leading to injury, hospitalization or death.³ Fortunately, individuals who obtain aid within 1 hour of a fall have a 50% increased survival rate compared to individuals who obtain aid after 72 hours.⁴ Thus, devices that have the ability to detect falls and alert proper personnel could serve to help lower the consequences of falling for individuals with a lower-limb amputation.

A number of studies have developed body worn sensors that can detect fall events. These devices primarily use inertial measurement units (IMUs) to record signals from 3-axis accelerometers, gyroscopes, and/or magnetometers. Individuals with a lower-limb amputation utilize a prosthesis that allows for fall detection sensors to be conveniently integrated within the prosthesis (e.g., directly attached to the pylon). However, it is not clear if such sensors are able to detect a wide range of fall types. Therefore, the purpose of this study was to investigate the accuracy of detecting different fall types with an IMU placed on an individual's shank in preparation for application and validation on individuals with a lower limb amputation.

Methods

IMU sensors (XSens, Enschede, Netherlands) were placed on both shanks of 15 healthy young adults in positions analogous to the pylon of a prosthesis distal to the knee. Tri-axis accelerometer and gyroscope data were recorded from these devices at 100-Hz while subjects completed an overground course with simulated falls and near-falls. The course was designed to simulate activities of daily living (ADL: walking/running in a straight line at a self-selected pace, navigating turns, sitting and rising from a chair, laying down and getting up from a bed, picking up an object on the floor, and ascending/descending stairs/slopes). Subjects performed 4 types of simulated falls: forward/backward trips (i.e., subjects walked forward/backward until they impacted a fall pad and fell) and left/right lateral falls (i.e., subjects stood with their left/right side adjacent to the fall pad while a lab technician pushed them until they lost balance and fell onto the fall pad). For the simulated near falls, subjects walked until their left/right foot struck the fall pad and then recovered from the stumble.

Raw data were analysed using the MATLAB Classification Learner Toolbox. First, data were split into two categories: ADL or Fall. Data were divided into 0.5 second windows with a 0.25 second overlap. During these 0.5 second windows, a total of 40 features were computed (Table 1). Data were randomly split into training (80%) and model verification (20%) sets for each subject and each category. Three different classification algorithms were used for activity classification and validated with 5-fold cross validation: support vector machine with a cubic kernel (SVM), K nearest neighbor with weighted dimensions (kNN), and a bagged decision tree ensemble (Tree).⁵

Table 1: Features extracted for each 0.5 s window for each accelerometer (accel) and gyroscope (gyro).

Vector resultant (r_{accel} , r_{gyro})	Median, Mean, Standard Deviation, Skewness, Kurtosis, IQR, Minimum, Maximum
Each axis (x_{accel} , y_{accel} , z_{accel} , x_{gyro} , y_{gyro} , z_{gyro})	Mean, Max, Min, IQR

To determine algorithm accuracy, a simple control scheme was created. First, models were implemented on the verification data set. A fall was identified if at least two adjacent windows contained a label associated with a fall. If this occurred within the duration of the fall (~1s), a correct fall classification was made. Falls were labelled by type: forward/backward trips and lateral falls with the sensor placed on the inside/outside leg. Finally, fall detection accuracy was calculated, defined as the number of correct classifications divided by total number of falls (Table 2).

Results and Discussion

Forward falls had the lowest detection accuracy for each algorithm. When falling forward, participants can more easily protect their body with their hands and knees, acting to reduce the acceleration on impact. On average, inside falls had the highest detection accuracy. The inside shank is often the first part of the body that impacts the ground during lateral falls, possibly contributing to the higher accuracy. This is in contrast to previous work that noted highest classification accuracy with backward falls when an IMU sensor is placed on the waist of each participant.⁶

Significance

This study highlighted that fall detection accuracy is not the same across fall types and classification algorithms. Future work should seek to improve detection of forward falls (e.g., placing sensors in different locations, implementing different classification algorithms such as threshold algorithms,⁷ and exploring different features) and validate these results on individuals with a lower limb amputation.

Acknowledgments

This work was supported by CDMRP W81XWH2010164.

References

¹Miller WC, et al. *Arch Phys Med Rehabil.* 2001. ²Kulkarni J, et al. *Physiotherapy.* 1996. ³Rubenstein LZ, et al. *Age Ageing.* 2006. ⁴Gurley RJ, et al. *N Engl J Med.* 1996. ⁵Pew C, et al. *IEEE.* 2018. ⁶Hwang SY, et al. *Int Conf on CS and Tech.* 2012.

Table 2: Accuracy for each type of fall and algorithm

	Type of Fall				
	Forward	Backward	Outside	Inside	All Falls
SVM	76.7%	93.3%	100%	100.0%	92.5%
kNN	73.3%	90.0%	90.0%	100.0%	88.3%
Tree	76.7%	86.7%	93.3%	93.3%	87.5%

Determination of fall risk for lower limb amputees

Log Number: OP190008

Award Number: W81XWH2010164



PIs: Richard R. Neptune, PhD, Shane R. Wurdeman, PhD, CP **Org:** The University of Texas at Austin **Award Amount:** \$346,373 4/2020 to 3/2022

Study Aims

- Establish an initial fall detection algorithm derived from simulated falls in a laboratory setting (Aim 1).
- Utilize and refine the initial laboratory-based algorithm to provide detection of fall events during activities of daily living in pragmatic, real-world environments (Aim 2).

Approach

- Conduct a human subject experiment to create a baseline algorithm from control and amputee subjects performing simulated falls in the laboratory setting (n=30 control, n=5 amputee).
- Conduct a human subject experiment using lower limb amputees to refine the algorithm for use in real-world environments (n=40 amputees).
 - Amputees will wear the sensor for 8-weeks during their normal daily living activities.
 - Fall events will be reported weekly to provide iterative updates to the detection algorithm.



AT&T LTE Activity Device motion sensor. This sensor contains 3-axis accelerometer, gyroscope and magnetometer to measure human motion and can upload data to the AT&T cellular LTE network in real-time.

Timeline and Cost

Activities	CY	1	2
Perform in lab testing (n=35) to produce an initial fall detection algorithm.		Aim 1	
Perform real-world experiment (n=40) to evaluate and update the initial fall detection algorithm.			Aim 2
Estimated Budget (\$K)		\$186	\$160

Goals/Milestones

CY1 Goals – Project initiation

- Complete IRB approval
- Complete Aim 1 experimental protocol
- Begin analysis of data (Aim 1)
- Begin recruiting for Aim 2 protocol
- Disseminate initial results

CY2 Goals – Testing, analysis and recruitment

- Complete human subject recruitment and testing (Aim 2)
- Complete analyses of data (Aims 1 and 2)
- Complete results dissemination

Budget Information:

Projected Expenditures: \$346,373

Actual Expenditure: N/A

Updated: July 30, 2020