Using a Socially Assistive Robot in Gait Recovery and Training for Individuals with Cognitive Impairments

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Abstract

This paper describes a new methodology for gait training and recovery for people in mid- and late-stage dementia. A combination of social and rhythmic auditory cues is used to express the robot's behavior. Specifically, the described research develops and evaluates a method for on-line adaptation aimed at both personalizing the therapy process and maximizing its health-related outcomes. This novel user activity sensing approach provides the rationale for development of socially assistive robotics therapy for monitoring and coaching users toward customized and optimized recovery and care programs.

Introduction

Physical rehabilitation therapies that focus on motor activities help individuals with dementia to rehabilitate damaged functions and maintain their motor abilities so as to keep the greatest possible extent of autonomy. Motor capabilities generally deteriorate more slowly than verbal and cognitive skills with this population (Howieson et al. 1997) and many efforts are usually directed toward maintaining and preserving these abilities. Physical strength and flexibility deterioration increases with age and can lead to falls, the precursor to the most common medical injuries suffered by older adults (Province et al. 1995). It was demonstrated and experimentally validated that the motor impairment in people in mid- and late-stage dementia affects walking cadence (Camicioli and Licis 2004), but it was also shown that the hazards of discontinued walking are equally harmful. Walking is essential for the physical health of persons suffering from dementia who lose their psychomotor skills with the progression of the disease. Gait analysis has been studied with a variety of tools and techniques (Cappozo, 1984). More recently, researchers have looked at the best way to

This work is supported by the USC NIH Aging and Disability Resource Center (ADRC) pilot program and National Academies Keck Futures Initiative program. We are also grateful to our partners: Silverado Senior Living and The Jewish Home Los Angeles.

methodologically combine input from health professionals with the capabilities of newer technologies (Davis 1988). We seek to use our novel technology to assist in the maintenance and recovery of walking capabilities for these affected populations.

In this work, we propose to use a multi-modal system that combines Rhythmic Auditory Stimulation (RAS) (Thaut 1997) with other social cues expressed through an assistive robot's behavior and personality, so as to test the effect on gait characteristics of persons in mid- and late-stage dementia. RAS provides auditory cues that facilitate gait characteristics such as an appropriate walking cadence along with enhanced velocity and stride length. A lightweight motion capture suit is used to non-invasively measure and analyze the user's gait. The gait data provided by the motion capture device are used as input to the robot's behavior control architecture that allows the robot to adapt its behavior with respect to the user's gait characteristics. The robot will serve as a gait trainer and therapist and will try through its motivating adaptive behavior to enhance user gait characteristics. In addition to serving as a physical trainer, the robot will also be capable of providing detailed reports of patient progress to caretakers, physicians, and therapists.

Hypothesis

This study is designed to test the role of robot in physical therapy for gait and locomotion training, recovery, and improvement.

Hypothesis:

The social robot's ability to encourage and motivate, combined with the use of Rhythmic Auditory Stimulation (RAS), can improve gait characteristics (cadence, velocity, and stride length) for people suffering from dementia.

Experimental Test-bed

The robotic test-bed used for this experiment is a humanoid torso mounted on a Pioneer mobile platform (Figure 1). The robot base used is an ActivMedia Pioneer 2DX equipped with a speaker, a Sony Pan-Tilt-Zoom (PTZ) color camera, and a SICK LMS200 eye-safe laser range finder. The biomimetic anthropomorphic version of the setup involves a humanoid torso, mounted on the same mobile base (Figure 1), and consisting of 22 controllable degrees of freedom, which include: 6 DOF arms (x2), 1 DOF gripping hands (x2), 2 DOF pan/tilt neck, 2 DOF pan/tilt waist, 1 DOF expressive eyebrows, and a 3 DOF expressive mouth. All actuators are servos allowing for gradual control of the physical and facial expressions.

We are particularly interested in using the humanoid's anthropomorphic but not highly realistic appearance as a means of establishing user engagement.



Figure 1. Human-like torso mounted on a mobile base

We have also designed a new inertia-based motion capture suit. To ensure that the suit is minimally invasive and to minimize the burden on the user, we have taken special care to minimize the size and weight of the components. To this end, we have developed new inertial measurement units (IMUs) to be worn by the study participants. In comparison to other IMU-based systems (e.g., Miller et al. 2004), our new version has drastically lower weight (35g) and size (35cm³). The computational techniques used to process the motion capture data ensure accurate, real-time activity recognition. Specifically, we have developed a new algorithm for segmenting the data output of the IMUs. This algorithm relies not only on more traditional temporal segmentation techniques, but also uses a relatively new technique for geometry based segmentation. This addition affords us the ability to examine our motion data with varying levels of granularity, which in turn expedites the process by which we recognize the user motion.

Experimental Design

The main goal of this work is to improve and maintain gait through the use of the Rhythmic Auditory Stimulation (RAS) methodology combined with the robot's social behavior. Based on our previous work and pilot studies, we expect the appearance and behavior of the robot to serve as an additional motivating factor to keep users interested and invested in the rehabilitation activity (Tapus et al. 2008). The main criterion in this experiment is the locomotion rating. Before starting the experiment, the Functional Independence Measure (FIM), a standardized instrument for functional assessment, will be used to determine the participant's locomotion level. The FIM responses are as follows: locomotion level 0 (no assistance for walking), locomotion level 1 (one person assistance), and locomotion level 2 (two person assistance). Based on the FIM responses and evaluation by health professionals, we will determine the chief deficiencies in the user's gait, and in turn, the characteristics we will seek to improve during the remaining sessions.

This session will be repeated twice weekly for a period of at least 3 months (or a minimum 12 weeks). This study is intended to be longitudinal in order to verify any long-term effects of the robot therapist combined with stimulating auditory cues. In order to verify the improvement level, a baseline for the gait will be calculated in the first of the twelve sessions. In this baseline session, the participant will be asked to walk on a path of 18 meters, with no robot present. The first 3 meters will be considered as warm-up, and the final 15 will be used for analysis. The parameters that are recorded during the baseline session are the following: cadence, velocity, and stride length. These parameters are measured by using the motion capture device worn by the participant on the lower legs. Also, a comparison between a group of elderly participating in the Robot Locomotion Therapist (called RLT group) and a control group of elderly with similar gait deficiencies who will not participate in the Robot Locomotion Therapist (called non RLT group) will be conducted. The non-RLT group will not perform any gait exercise. This comparison is done to observe the benefits of this physical therapy for the gait maintenance and improvement.

The participants in the RLT group will interact with the human-like robot (see Figure 1). During the experiment the robot will ask the participant to walk for a distance of 18 meters in a straight line. A line will be drawn on the floor. The robot will modify and adapt its behavior so as to maximize the user's cadence and velocity. Three parameters will be used to define the robot's behavior and will be adapted by using the Policy Gradient Reinforcement Learning (PGRL) algorithm (Tapus et al. 2008). These parameters are: personality style (encouraging ("I'm not doing much to help! Great job!")

vs. nurturing ("You are doing better today.")), speed and amount of movement, and music played. The music played parameter has three sub-conditions, consisting of: (1) rhythmic cues (based on user's cadence and velocity) embedded in the music, (2) rhythmic cues (based on the user's cadence and velocity) provided by an electronic metronome, and (3) no auditory stimuli. Music selection will be based on the participant's musical preference. Two recordings will be created for each participant, based on his/her cadence – these recordings will be: (1) with music and audible rhythmic beats; and (2) with metronome beats alone. The volume of the music and the robot's voice will be set at a high, yet comfortable level as determined by the nurses. The robot will be facing the participant and will move backwards (away from the user), at 1.5 meters.

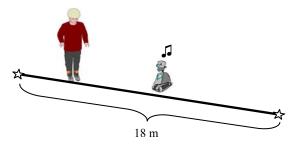


Figure 2: Gait Training by using a robot and the Rhythmic Auditory Stimulation (RAS) – Experimental Setup

Evaluation

The participant's locomotion maintenance and improvement will be assessed (e.g., cadence, velocity, and stride length) using both data obtained from the motion capture device, and data obtained from video recordings. Outcomes will be quantified by evaluating task performance and time to travel the fixed distance. Due to the nature of abnormal gaits, the details of what constitutes improvement can vary drastically. In general, we will seek to increase stability. This may correspond to changes (increases or decreases) in walking speed, cadence, and stride length. Again, input from physical therapists will be used to assess the relevant characteristics for signs of improvement.

Experimental Results

Two focus groups were conducted at our partners' sites: Silverado Senior Living and The Jewish Home of Los Angeles. The preliminary focus groups demonstrated the necessity of such a system for gait recovery and training. They also indicated that many residents seemed excited about the possibility of working with a human-like robotic assistant. Furthermore, input from medical professionals at the facilities indicated the need for an effective, easy-to-use gait analysis tool. The focus group insights were used to

design the hypothesis-testing experiment. More experimental results validating our hypothesis will be available by the time of the workshop, as this paper reports on ongoing work in progress.

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