Game Theory:
A Potential Tool for the Design and Analysis of Patient-Robot Interaction Strategies

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ABSTRACT

Designing suitable robotic controllers for automating movement-based rehabilitation therapy requires an understanding of the interaction between patient and therapist. Current approaches do not take into account the highly dynamic and interdependent nature of this relationship. A better understanding can be accomplished through framing the interaction as a problem in game theory. The main strength behind this approach is the potential to develop robotic control systems which automatically adapt to patient interaction behavior. Agents learn from experiences, and adapt their behaviors so they are better suited to their environment. As the models evolve, structures, patterns and behaviors emerge that were not explicitly programmed into the original models, but which instead surface through the agent interactions with each other and their environment. This paper advocates the use of such agent based models for analysing patient-therapist interactions with a view to designing more efficient and effective robotic controllers for automated therapeutic intervention in motor rehabilitation. The authors demonstrate in a simplified implementation the effectiveness of this approach through simulating known behavioral patterns observed in real patient-therapist interactions, such as learned dependency.

Keywords: *Automated Therapeutic Intervention, Game Theory, Patient-Robot Interaction Strategies, Rehabilitation Technologies, Rehabilitation Therapy*

1. INTRODUCTION

There are numerous movement-based motor rehabilitation devices commercially available which have proven to successfully aid the recovery of patients suffering hemiparesis after stroke (Bouzit, Popescu, Burdea, & Boian, 2002; Gomez, 1997; Muto, Herzberger, Hermsdörfer, Miyake, & Pöppel, 2007). Robotic movement-based rehabilitation therapy has many advantages over conventional manual rehabilitation, such as; reducing the burden on the healthcare system, the ability to deliver low cost well controlled repetitive training sessions, and quantitative assessment of motor recovery (Banala, Kulpe, & Agrawa, 2007). However, the major drawback over manual rehabilitation is the loss of human insight and intuition which is used by the therapist to regulate how and when assistance is offered to a patient. Current

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control system approaches do not take into account the highly dynamic and interdependent nature of the relationship which exists between a patient and their therapist. For example, an experienced therapist will very quickly notice when a patient is making less effort to engage during periods of assistance. In such cases the therapist may reduce the amount of assistance they offer in order to coax more effort from the patient. This is an example of a strategy adoption by the therapist based on their experience of the patient's behavior. In the same situation, a robotic controller lacking the therapist's experience might increase the level of assistance to such a patient in a naïve attempt to provide assistance. This action is counterproductive since the robot is taking more of the rehabilitation burden from the patient who can complete their task with less effort than they have the ability to offer. In such cases the patient is no longer contributing maximum effort and the resulting therapy will not be as efficacious.

1. Introduction to Common Rehabilitation Robotics Control Strategies

One of the most common controller strategies used in robotic rehabilitation therapy systems is the fixed kinematic control approach. Research suggests that the fixed kinematic control strategy is suboptimal because it abolishes variability, an intrinsic property of neuromuscular control (Jezernik, Scharer, Colombo, & Morari, 2003). A significant concern is that this strategy may force the central nervous system into a state of "learned helplessness" (Grau, Barstow, & Joynes, 1998; Wool, Siegel, & Fine, 1980) since the neural systems are not being challenged to explore alternative motor patterns on their own accord.

A more intuitive controller based on the "assist-as-needed" (AAN) paradigm is also widely used by movement-based rehabilitation robots. A comparison study of the efficacy of fixed trajectory algorithms against AAN algorithms on recovery of locomotion ability in completely spinalized adult mice was undertaken by Cai et al. (2006). The results of this study show that mice undergoing AAN robotic training exhibited faster and more pronounced recovery than mice given fixed robotic training. However, the paper concludes that an exact optimal AAN algorithm still needs to be developed. We believe that approaches such as AAN can be improved further through a better understanding of the complex dynamic interactions that exist between patient and therapist during periods of assistance. Current approaches ignore the complexity which drives a patient's actions, motivation and behavior in response to their therapist's assistance and therefore is not sufficient for administering optimized therapy. We feel that understanding these dynamics is crucial to developing rehabilitation systems that can offer quality recovery matching that of a competent therapist. Here we advocate the use of agent-based modeling for analysing patient-therapist interactions with a view to designing more efficient and effective robotic controllers for automated therapeutic intervention in motor rehabilitation.

2. Introduction to Agent-Based Modeling and Game Theoretic Principles

Agent-based modeling and simulation (ABMS) is a relatively new approach used to model complex systems composed of interacting 'agents' (human or otherwise). These agents are often described by simple rules and behavior for interacting with other agents and completing tasks. The main strength behind this approach is the principle of self-organization. Agents learn from their experiences, and adapt their behaviors so that they are better suited to their environment. As the models evolve, structures, patterns and behaviors can emerge that were not explicitly programmed into the original models, but instead surfaced through the agent interactions with each other and their environment (Macal & North, 2010).

A typical agent-based model is made up of three components:

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