Understanding the Relationship Between Baxter Robot Approach to Contact Parameters, Perception of Safety, and Contact Dynamics

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***Abstract*– It is expected that there will be a rise in stroke patients without a sufficient rise in care professionals and facilities for rehabilitation. Robot-assisted therapy is one solution, but it must be conducted safely. This project analyzed how speed relates to perception of safety when a robot is acting as a physical therapist assisting a patient with a task. The project also showed patterns associated with contact dynamics using 'lossy' fiber optic force sensors. These identified how the Baxter robot recognizes when it has made contact with a patient and informed how to make therapeutic human-robot interactions be perceived as safe.**

***Index Terms*– Baxter Robot, Human-Robot Interaction (HRI), Rehabilitation Robotics, Upper Limb Stroke Rehabilitation**

I. INTRODUCTION

Approximately 795,000 adults in the United States experience a stroke every year. While strokes can occur at any age, 62% of stroke hospitalizations in 2014 were present in patients above the age of 65 [1]. As the population of adults over the age of 65 grows due to longer life expectancies in the United States, this suggests a greater need for stroke rehabilitation, including physical therapy [2, 3]. Task-oriented physical therapy, specifically, has been shown to lead to improved quality of regained movement for upper-body stroke rehabilitation [4]. With increased demand, it is likely that there will be limitations in the number of facilities and physical therapists available.

One solution for this limitation is robots, such as the Baxter robot [5, 6], a humanoid robot originally used for industrial purposes, which can assist with physical therapy exercises and allow for patients to conduct their exercises safely without a physical therapist present. Wang, et al. [7] investigated Baxter's ability to make the decision to switch from observer to helper mode. This work was done via creating a trajectory with acceptable deviations for a patient's arm in a given task; sensing the location of the patient's arm was done via inertial measurement units (IMUs), such that if a patient veered away from the trajectory for too long, Baxter would assist with the task. This project, however, did not include a sensing component characterizing the contact between Baxter and the patient.

As robots become more common in daily life, industrial applications, and medical spaces, more research has been conducted regarding human-robot interaction (HRI). The focus of HRI projects is often to analyze how humans and robots can interact safely. These projects take into account parameters such as speed of interactions, torques/forces applied, robot position, and robot vision [8]. In an effort to establish a safe model for HRI, previous works have declared the onset of pain to be an acceptable maximum injury threshold [9].

More research needs to be conducted to understand how a robot therapist can safely provide assistance to a patient, as many HRI models and projects relate to industrial robotics as opposed to healthcare ones. This project examines how the Baxter robot can characterize contact dynamics between observer and helper roles to provide assistance in task-oriented stroke therapy in a manner that can be considered "safe" by relating speed to a perception of safety.

II. BACKGROUND

A. Stroke and Rehabilitation

Stroke is a neurological condition which can affect many of a patient's systems, including, but not limited to, motor and cognitive skills. Often, only one side of a person's body is affected. One primary treatment for stroke rehabilitation is physical therapy. Task-oriented therapy is a subtype of physical therapy in which the patient engages in exercises that accomplish a task, often for activities of daily living (ADL) [4].

When examining therapist-patient interaction in task-oriented physical therapy, it has been shown that there are roles that patients and therapists take on (Fig. 1), and that there are physical or verbal cues that initiate switching between those roles [10]. These cues include “stabilizes”, “guides”, and “expresses agreement” for physical therapists, and “does not reach”, “does not initiate”, and “requests” for patients. This project analyzes how the Baxter robot can characterize physical cues when switching from the therapist role of observer to helper.

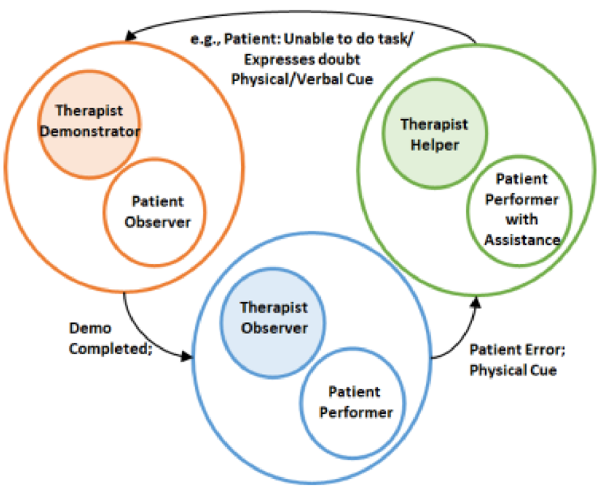


Fig. 1: Description of therapist and patient roles in physical therapy, including examples of cues that prompt switching between roles [10].

B. Contact Dynamics and Perception of Safety

Contact dynamics can be expressed in terms of whether or not there is any physical contact between the therapist and their client, or a robot and its user, as well as how the therapist is interacting with their client. The analysis in this paper addresses the interactions between a physical therapist and their client by relating speed of interactions to a perceived level of safety.

Perception of safety refers to a person’s idea of whether or not a system is safe, regardless of if it actually is. Case et al. found that the onset of pain varied between subjects, with the average being about 27N of force applied [9]. Keeping interactions under this amount would make a system safe, but whether it is perceived as safe relies on a variety of factors including trust, reliability in actions, and “perceived humanlikeness” [11].

C. Baxter Robot

Baxter is a humanoid robot made by Rethink Robotics, commercially used for manufacturing [5]. Baxter is equipped with two 7 degree-of-freedom arms and a two degree-of-freedom head (Fig. 2). The Robot Operating System (ROS) is used to operate Baxter, with most of the code being written in Python.
Pre-programmed joint trajectory recording and playback files were used to construct trajectories of Baxter assisting tasks in this paper.

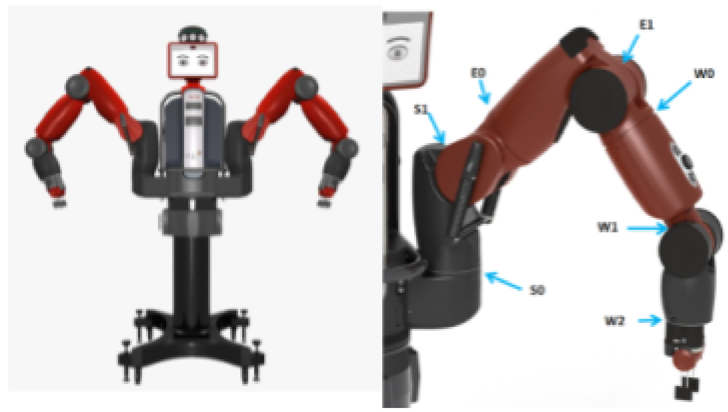


Fig. 2: Baxter torso atop mobile pedestal (left) and description of Baxter shoulder (S0, S1), elbow (E0, E1), and wrist (W0, W1, W2) joints (right).

D. Fiber Optic “Lossy” Sensors

Lossy force sensors are used throughout this project as a means of detecting force and contact. These sensors operate using optical lace: a 3D printed structure through which a wire capable of transmitting light is threaded through. Previous works have characterized the use of deflection of light in polyurethane wires as sensors for various uses, including pressure [7, 12].

III. METHODS AND MATERIALS

A. Experimental Setup

In this experiment, the Baxter robot assists a realistic nursing mannequin [Nursing Anne Simulator, Laerdal Medical Co., Norway [13]] with a drinking/reaching task. The task was chosen based on previous works conducted by the lab as a simple task Baxter can assist with [6]. In this task, the patient (mannequin) was seated across from Baxter with a table in front of them (Fig. 3). At the beginning, Baxter started with its arms at its sides. When the patient was unable to lift their arm, Baxter approached from below and used its end effector to lift the patient’s arm, then placed it back on the table. This process occurred twice in each trial.

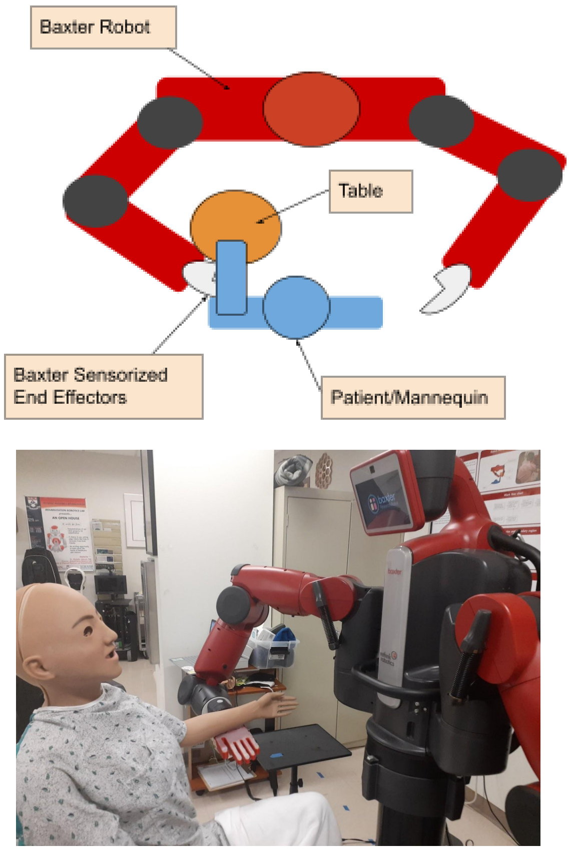


Fig. 3: Top-down view of experiment setup diagram (top) and photo of actual experimental setup (bottom).

In order to relate speed to perception of safety and contact dynamics, Baxter performed the same task in two modes: a slow mode and a fast mode. In both modes, five trials occurred. Baxter was 'taught' these tasks via the "joint recorder" and "joint trajectory file playback" examples, which come installed on the Baxter Research Robot [14].

B. Baxter End Effectors

Baxter's end effectors that were used were 3D printed hands, made with PLA. The inner side of the hand, which comes into contact with a patient, had soft rubber padding to make contact more comfortable. There were sections in the palm and fingertips that had a deeper cutout than the rest of the inner hand, which allowed for a sensor or extra padding. In the palm of the end effector was a lossy sensor (Fig. 4).

C. "Lossy" Sensors

While trials were occurring, data was being collected from "lossy" optical lace sensors in Baxter's end effectors via an Arduino Uno. An optical fiber [Stretch Magic, Pepperell Braiding Co., MA] was threaded through a lattice-like structure designed to fit in the lower palm cutout of Baxter's end effector. The lattice was printed using FormLabs Flexible 80A Resin so it would be soft to touch. Each piece of the lattice was a 7mm by 7mm by 7mm cube with supporting "X" shapes on the sides.

Fig. 4: Photo of Baxter end effector with lossy sensor embedded in palm and silicone.

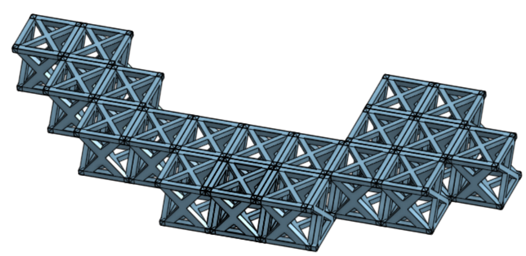


Fig. 5: CAD model of lattice structure for optical fiber, modeled using OnShape.

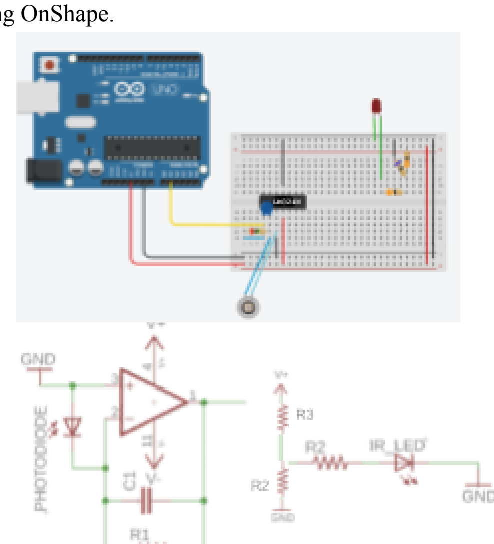
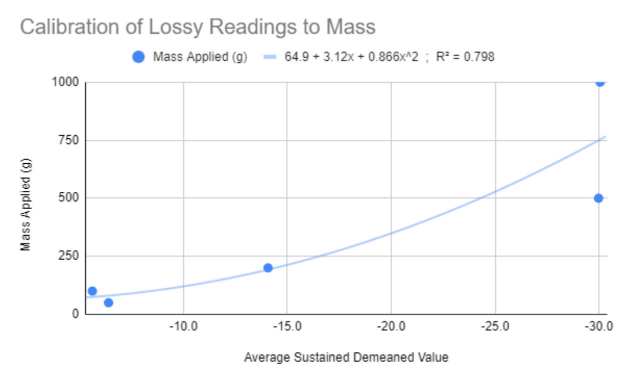


Fig. 6: Tinkercad diagram of sensor circuits (top) and schematic view of each circuit (bottom). The resistors used are as follows: R1= 2MΩ, R2= 33Ω, R3= 68Ω. The capacitor used is 4700pF. V+ is 5V, and V- is 0V.

The circuits used for this sensor were adaptations of the ones in [13]. The transmitting end was a simple infrared LED circuit with a voltage divider. The receiver was a photodiode current-to-voltage circuit. Data from the photodiode was read as analog values by an Arduino Uno. Circuit diagrams are shown in (Fig. 6).

IV. RESULTS

Calibration of lossy sensors concluded that the setup was more reliable when the sensor itself was uncovered and contact was directly applied to the sensor. Plotting the mass applied and average sustained analog value (demeaned from baseline value) yielded a parabolic line of best fit (R^2= 0.798) to approximate the relationship between sensor values and force applied (Fig. 7).



f(a) = force applied (N) ; a = analog value (demeaned)

$$y = 0.866a^2 + 3.12a + 64.9$$

$$f(a) = y * 10^{-3} * 9.8$$

$$f(a) = 0.0086828a^2 + 0.030576a + 0.63602$$

Fig. 7: Graph relating sustained and demeaned analog lossy readings to mass applied during calibration (top) and adjustment of equations to relate readings to force (N) (bottom).

In both the fast and slow movements, initial and sustained contact were noticeable using the lossy sensors, with contact due to the slow movement being larger and of longer duration. The following approximate forces were determined: fast movement contact: 1.0N±0.18, fast movement sustained: 1.4N±7.2, slow movement contact: 2.6N±1.2, slow movement sustained: 20N±11. The forces across the entire interaction, as well as Baxter's role, can be viewed in Fig.8.

V. DISCUSSION AND CONCLUSION

Results show that forces applied in these interactions are within the acceptable contact threshold (27N) as examined in [9], which suggests that these interactions were safe. In some individual trials, sustained force was above the contact threshold, but no contact force was above that threshold.

The objective of this project was to examine how the Baxter Research Robot can characterize contact dynamics in a stroke therapy setting using lossy force sensors, as well as correlate speed and force to safety of interactions. These objectives were fulfilled. Because contact was distinct in both movements, as well as across multiple force applications, this sensor could be used to characterize contact dynamics in robot-assisted therapy.

More research should be conducted to analyze sensor behavior in more complex movements and using a standard useability scale to examine if patients perceive physical therapy interactions with Baxter as safe. By analyzing more complex movements, it is hoped that a more thorough and informed analysis can be conducted relating calibration of lossy sensors and reliably correlating their readings to a measure of force applied.

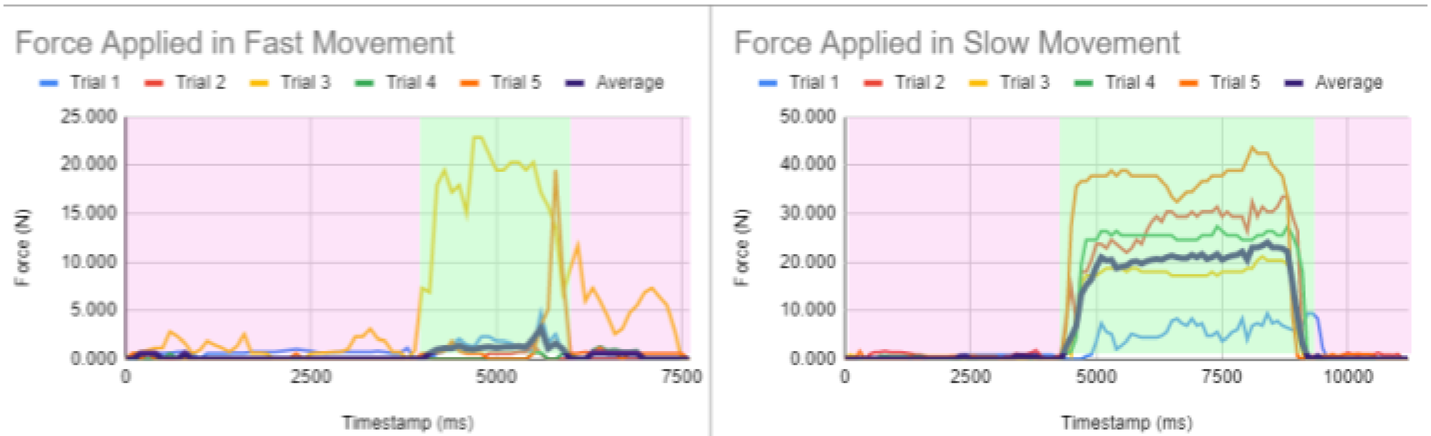


Fig. 8: Graphs depicting how much force is recorded from lossy sensors in fast (left) and slow (right) movement trials. Overlaid is Baxter's actions and role as a helper (green overlay) or observer (pink overlay).

This analysis would lead to Baxter's eventual ability to make decisions regarding the safety of interactions with patients. Some limitations to this testing include more complex motions being difficult for Baxter to learn and calibration of sensors being affected by lighting throughout the motion of the task.

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