Navigator: 2 Degree of Freedom Robotics Hand Rehabilitation Device

Design Team
Ray Adler, Katherine Bausemer, Joseph Gonsalves, Patrick Murphy, Kevin Thompson

Design Advisors
Prof. Constantinos Mavroidis, Prof. Mark Sivak, Qing Chao Kong

Abstract
There are no affordable hand rehabilitation devices on the market for patients who suffer from upper limb impairmnet due to stroke. The design team has succesfully developed a low cost hand rehabilitation device named the Navigator for home use that exercises finger flexion and extension (grasp and release) as well as wrist pronation and supination (rotation). Simultaneous wrist rotation and grasping motions are required for many daily tasks. A previous prototype (HERRI) exists that is capable of excercising these motions, but it is large, expensive and is intended for clinical settings. The new device is self contained, low cost, lightweight (<7 kg) and is to be used in the home. Like the HERRI, the Navigator will connect to a computer so that users can play a game to facilitate rehabilitation and to provide users and clinicians with objective rehabilitation data. In the final design, a rack and pinion powered by a DC motor facilitates the linear flexion and extension of the fingers while a belt and pulley powered by a second DC motor facilitates the rotational pronation and supination of the wrist. An encoder, potentiometer, and torque and force sensors will be used to track user inputs and device outputs. The control system features an Arduino microcontroller that facilitates device inputs and outputs so that users can play a virtual reality game as part of therapy.

For more information, please contact mavro@coe.neu.edu.
The Need for Project

Roughly 795,000 people in the United States suffer from stroke annually, and it is the leading cause of long-term disability in the nation. Of these stroke patients, 85% have arm impairment, and 55-75% retain that arm impairment after 3-6 months. Currently, there are no at-home robotic hand therapy devices that are able to accurately mimic daily tasks. Pronation and supination (rotation) of the wrist, with simultaneous flexion and extension (grasp and release) of the fingers, are required for many fine motor daily tasks. Because time with rehab therapists is limited, a device capable of exercising these motions that could be used in the home would be beneficial to patients suffering from hand impairment [Rep. 1.2]. The Navigator is low cost, capable of exercising these motions and is safe for use without a rehab therapist. Another benefit of the Navigator is its virtual reality interface. As patients exercise with the Navigator, they will play a virtual game. Rehab devices that have a virtual game component have been shown to increase the rate of recovery in stroke patients with limb impairment.

The Design Project Customer Needs and Specifications

Customer Needs

The goal of the Navigator project is to build a device that can bring a higher quality of rehabilitation to those who suffer from upper limb impairment due to stroke and brain injury by combining 2 DOF of motion with virtual reality in order to restore their ability to complete daily tasks.

In order to identify customer needs, the team interviewed experts with industry, clinical and research backgrounds [Rep. 3.1]. These interviews showed a need for a low-cost, portable device for at-home use capable of simultaneously exercising grasp and release motions of the fingers and rotation of the wrist. Additionally, the device needs to facilitate the full, healthy range of motion for the exercises it provides with imperceptible response times. The device should also be intuitive and easy to use.

Design Specifications

The Navigator is optimized for home use and includes the following features:

- Small tabletop footprint (<0.16 m² footprint)
- Fast and simple set-up (<3 min setup time)
- Light weight (<7 kg)
- Low cost (<$3000 prototype cost)
- Connectivity to home computers
- Interface with a computer game to improve quality of therapy
Design Concepts Considered

Three rotational and four linear initial concepts were proposed. Using a design matrix, these concepts were evaluated based on their weight & size, functionality, friction, cost and manufacturability. Each criterion was weighted equally in the ranking. The best performing concepts were then selected. For the linear concept, a rack and pinion system was selected and a belt and pulley system was selected for the rotational concept. Each selection is powered by a DC motor and features a series elastic element. Series elastic actuators (SEA) have been shown to successfully reduce backlash in human systems and improve back drivability and shock absorption. The series elastic elements in each system have a modular design so that the system will function without them if necessary.

Sensors for linear and rotational position, force, and torque measurements were also selected using design matrices and criteria. Over 60 sensors were specified and evaluated. A linear slide potentiometer was selected as the linear position sensor and a rotary optical encoder was selected to track the rotational position of the user. Strain gauge force and torque sensors were selected for the force and torque measurements.

The closed loop control for the system is achieved using an Arduino microcontroller. Arduinos are low cost (~$50), simple to use, and can integrate with USB. In addition, they can be purchased with varying numbers of digital and analog inputs and outputs, so it was simple to purchase one that fit the project specifications.

Figure 1: Final Design Concept
Recommended Design Concept

The finalized design is made up of three major subassemblies; the linear drive (top), the rotational drive (middle) and handle (bottom) which are shown at left in Figure 2. The linear drive functions by receiving the users grasp and release motion at the handle. The motion is translated through the shaft of the handle to the rack and pinion which in turn translates the motion to the motor. The input force and position is measured by the load cell and potentiometer respectively. The rotational drive functions by receiving the user’s wrist torque outputs at the handle. As the user turns the handle, the motion is translated from the handle shaft to the motor shaft by the timing pulley. The torque and position is measured by the torque sensor and encoder as the motor shaft turns. The handle subassembly is the point of interaction between the robot and the patient, so it was optimized for user comfort. The palm rest is contoured to the human palm and the finger grip features rolling contacts. These rolling contacts facilitate pure finger flexion and extension and minimize wrist use when performing the grasping motion so that the user can comfortably exercise grasp and wrist rotation simultaneously. The handle also features modular attachments for multiple pinch exercises.

The electronics of the Navigator are made up of the motor controllers and power supplies for each degree of freedom, the Arduino microcontroller, as well as the amplifiers for the torque and force sensors. All electronics will be included inside the device to increase safety, portability and attractiveness of the finalized design.

Ansys was used to simulate the worst case loading scenarios in both the linear and rotational subassemblies. The analyses showed under worst case specified loading (user input of 50N) that the linear subsystem has a safety factor of 4.5 (Figure 3). The rotational subassembly has a safety factor of 3.8 under worst case loading (1.6 N-m user input).
The recommended Navigator design is advantageous because it can accommodate high force and torque inputs yet it is compact and lightweight, allowing it to be used on a desktop in the home. While the previous device could accommodate a wide range of user inputs, it was not self-contained or designed for home use.

**Financial Issues**

The Navigator will affect several markets including rehabilitation, telemechanics and videogame control. Currently, there are no rehabilitation devices on the market that offer the same combined motions exercised by the Navigator. The overwhelming number of people experiencing stroke induced upper limb impairment is ever increasing. The non-robotic rehabilitation technology available to most patients is primitive and is only effective up to six months after the stroke occurs. Robotic rehabilitation is effective after this six month period and with a projected market price of $400, the Navigator is sure to affect not only the market, but also the lives of patients who use it.

**Recommended Improvements**

The main goal for the Navigator project is to market a finalized product as soon as possible. Work on the version 2 prototype will begin January, 2013 to facilitate a fast transition from the lab to the consumer market. Work on the version 2 prototype will begin January, 2013 to facilitate a fast transition from the lab to the consumer market. The goals for the second version include optimizing weight, size and cost, adding advanced controls and designing compatible virtual rehabilitation games. Achieving all of these goals will facilitate a fast transfer from the design laboratory to the marketplace so that consumers will have an effective hand rehabilitation option for the home.