

# DOMESTIC REHABILITATION AND LEARNING OF TASK-SPECIFIC MOVEMENTS

Yoky Matsuoka, Harvard University  
Larry C. Miller, Boston Biomotion Inc.

## Abstract

We have constructed a device that is suitable for domestic task-specific rehabilitation. The machine has a large workspace permitting natural three-dimensional movements. It is unique because it is inherently safe but still allows force-velocity collinearity and force amplitude variation within one movement. These real-life motions in a software-controlled environment make task-specific rehabilitation possible under the complete volition of the user. Furthermore, the machine can operate without constant supervision due to its software control features and its hardware's inherent safety and flexibility, making it the perfect candidate for domestic use.

## Introduction

Recently, the importance of computer assisted rehabilitation has been emphasized for improving performance and recovery time. Most robotic devices are designed to have a specific workspace for specific injuries with safety features included in the software. However, a human's normal movements cannot be matched well on these highly constrained devices and rehabilitating on such machines can result in muscle imbalance and the disruption of the underlying coordination structure. In

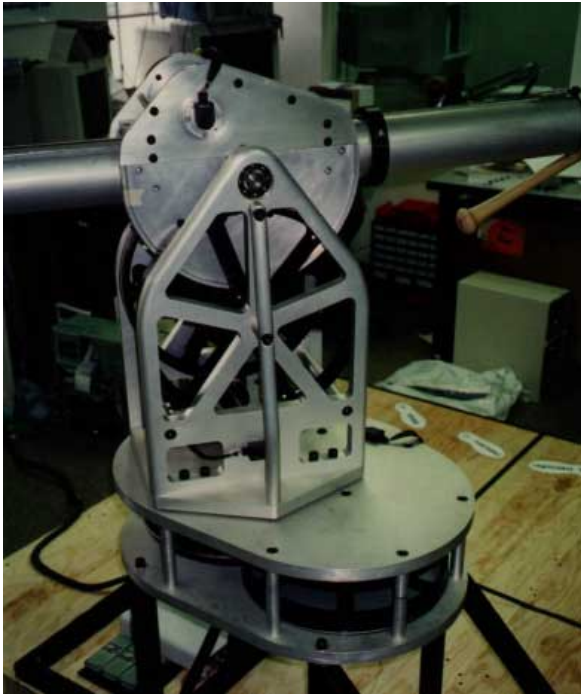
addition, in actively powered motion devices, the control software's inhibition of the hardware for safety can fail and cause severe injuries.

In order to overcome these problems, we have constructed a three-dimensional resistance rehabilitation machine that matches well to the user's kinematics and needs. This machine has no potential for machine-induced accidents and injuries.

## Device Description

The mechanical design of the device was motivated by the need to provide safe, repeatable, accurate, and smooth controlled resistance to the user over a large workspace. The device is designed to be purely dissipative and thus it is inherently safe. There are three actuated joints as shown in Figure 1: yaw and pitch rotary joints are combined with a linear joint to create a large 1.1meter radius half-sphere workspace.

Magnetic particle brakes are used for the actuators to provide accurate control over a wide range of speed and torque with a simple electrical current input. Each brake, a Placid Industries B-150, provides a maximum torque of 17 N-m. To accomplish over 500N maximum force, two cable-pulley speed reducers were designed. The



**Figure 1:** A picture of the rehabilitation device. There are yaw, pitch, and linear joints and they are cable controlled.

first stage has a 60mm diameter input pulley translated to a 390mm output pulley, and the second stage has 80mm input and 400 mm output pulleys. These two stages together create a reduction ratio of 32.5 : 1, producing the 550N-m output torque. This cable/pulley reduction strategy was chosen because it has extremely low friction and zero cumulative backlash.

Concurrently, to improve the performance of the machine under dynamic operation, the stiffness of the machine is calibrated with the cable diameters. The yaw joint is cabled with a single pair of 2.4mm antagonistic cables and the pitch joint

is cabled with two pairs of 3.2mm cables. The linear stage has a single pair of 2.4mm antagonistic cables wrapped around the brake shaft and attached to the ends of the linear stage tube. The resulting lateral stiffness is approximately 60 kN/rad (or 10mm deflection under 550N force at 1.1m extension), and the linear stiffness is 110kN/m (or 5mm deflection under maximum torque).

A three-degree-of-freedom non-actuated gimbal is designed as the primary interface tool for the machine. The gimbal has a removable handle that can be substituted with specific grips such as baseball and tennis as shown in Figure 2. In addition, the gimbal can be replaced with other couplers shown in Figure 3 to accommodate movements for various limbs.



**Figure 2:** The gimbal handle can be interchanged to activity specific grips such as the baseball handle.

The machine is controlled by a motion controller with a DSP, and is programmed to incorporate this interface. It converts the encoder readings to Cartesian coordinates and

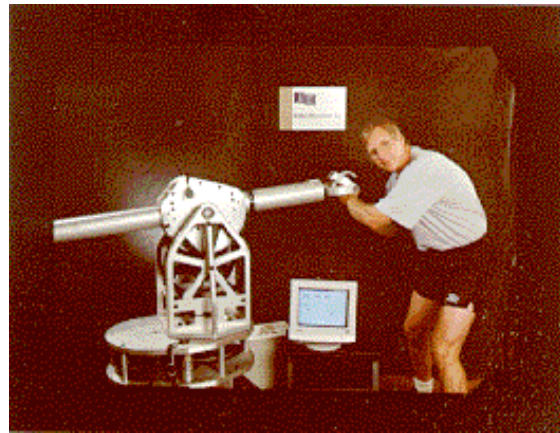


**Figure 3:** Various couplers can be used as the interface for the machine to rehabilitate or train various sets of muscles.

can respond to a user's musculo-skeletal changes in force, position, velocity, acceleration, power, work, and range of motion in real time. LabView™ software is used as the graphical interface and it allows the user to specify the training variables in a simple manner. A foot pedal is installed within the user's workspace to make fine adjustments or to send commands during training without stopping the motion. A picture of the overall machine in use is shown in Figure 4.

### **Task-Specific Training**

One of the biggest advantages of our new machine is the capability of three-dimensional task-specific training. The Principle of Specificity of Training states that “mimicking or replicating an activity of daily living in training assures that gains carry



**Figure 4:** A picture of the machine in use. The machine has three actuated and three non-actuated joints creating 1.1m half sphere workspace. This configuration allows most movements made by a strong and tall individual.

over precisely to the motion of interest.” With our machine, the user is freed from the line of action of the force constraint present in all current forms of resistance training.

For example, the line of action of the force in current weight training is always directed through the center of the earth, tangent to the arc of motion in rotary systems, or along the cable as shown in Figure 5. Human force production in such activities is highly constrained because of the need to

reconcile body position, joint axes, and leverage to the line of action of the force. With our device, the user has complete control over the force direction with end-point force-velocity collinearity. Force-velocity collinearity means that when one pushes on the endpoint, it moves and is resisted in the direction it was pushed. Research has shown that purposeful motion is degraded without force-velocity collinearity. Therefore when our machine is used, daily activities can be replicated in an entirely natural cause and effect environment without any machine specific constraints.

Furthermore, the magnitude of the force can be varied within one movement to accommodate the physiology of the user. In a curling

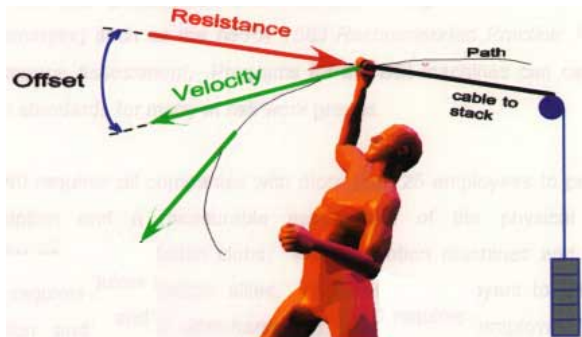


Figure 5: Most force resistance training devices do not preserve force-velocity collinearity. Force-velocity collinearity means that when one pushes on the endpoint, it moves and is resisted in the direction it was pushed. These offsets between resistance and velocity create an inefficient and dangerous environment for rehabilitation.

movement as an example, the biceps muscle can exert 71% of its potential when the arm is straight (180 degrees), 100% of its strength at 100 degrees and 67% at 60 degrees [1] as shown in Figure 6. The only way to match these muscle properties is to train with a variable resistance device. Our machine creates the force field that matches the strength of the muscle at each specific configuration to achieve maximum efficiency while eliminating injury. By keeping track of changes in the user's input, the applied force can be adjusted to be stronger or weaker as the training progresses.

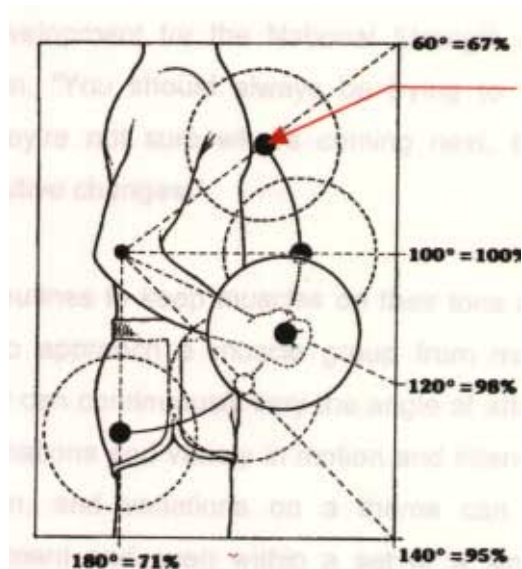


Figure 6: Variation in force relative to the angle of contraction [from Wilmore and Costill, 1994]. 100% represents the angle at which force is optimal. If the weight were matched to accommodate the strength at the 60 degree angle, the weight would be too light for other angles. However, if the weight is matched for 100 degrees, over-strain is inevitable elsewhere.

### **Domestic Usage**

This task-specific rehabilitation machine has another advantage. Due to its inherently safe hardware, the rehabilitation can take a place without full supervision. At the appearance of pain or fatigue, the user can instantaneously decrease the machine's damping or stop the motion. Because the machine exerts the resistive force only when the user applies force, the user experiences no loading when the motion is stopped.

In addition, the manipulator does not fall on the ground even when the user releases the machine because gravitation is compensated for internally. At the same time, if the machine receives a high impact, the machine acts like an inverse damper to accommodate the impact. Thus, if someone falls on the machine, the machine slows you down gradually as the body velocity decreases.

The advantage of a software based domestic machine is that the data of the rehabilitation training can be recorded and can be brought to physicians for an evaluation. In return, the physicians can assign the next training level in software according to the progress. This procedure assures that the patients do not make a mistake with the procedural settings. With the software assigned by the physicians, the machine can act as a virtual therapist.

Furthermore, the computer of the rehabilitation machine can be linked to the physician through the Internet. The physician can have on-line access to the user's musculo-skeletal changes and can vary the output of the machine as necessary.

At last, the installation of the machine at home is trivial because it is designed to disassemble into small manageable pieces.

### **Learning a New Task**

In addition to rehabilitating for a task that is already familiar, a new task or activity can be learned using the machine. Often, people with injuries or disabilities cannot try other activities because the level they have to start at is too physically demanding. With a software controlled low-inertia machine, the training can be conducted at any level for any activity.

This machine can enhance the life of people who are physically challenged. They will no longer be limited by their physical abilities and can participate in a certain activity at their own level. This is good for recreation purposes and for learning tasks that they never thought that they would. When those tasks are learned, they may be able to go out and actually try the non-virtual activities.

## **Challenges**

The constructed machine is a prototype and is not yet suitable for mass production. There are two issues that cannot be overlooked. First, the cost of the machine needs to be significantly reduced in order to target domestic usage. This work is already underway and it has been shown that the redesign of some components results in significant price reduction and eliminates bulkiness as well.

Second, the complete passiveness of the machine is an advantage for safety, but it limits the functionality of the machine. For example, if the end point of the robot is in the area where it should not be, the user must physically move it out of the area because the robot cannot store any energy to move itself. Currently, the interface program accommodates this problem by giving visual guidance of the movement paths. In the future, small active actuators or springs will be integrated to create the perception of active components. If active actuators are used, they must output very small torque even under its maximum current input to assure the safety of the machine.

## **Conclusion**

Our machine represents a revolutionary hardware platform. It allows large natural movements with force-velocity collinearity and

resistance variation. Previously a domestic rehabilitation device was impossible because of the safety issues and the need for supervision. With the combination of software-controlled supervisors and the inherent safety of the hardware, our device design allows rehabilitation to take a place at home. By working the muscles in synergy instead of isolation with robot assistance, recoveries will be faster and better in the future.

## **References**

[1] J. H. Wilmore and D. L. Costill "Physiology of Sport and Exercise", Human Kinetics Publishers, 1994.

## **Contact:**

Dr. Yoky Matsuoka  
Harvard University, Division of  
Engineering and Applied Sciences  
29 Oxford Street  
Cambridge, MA 02138  
yoky@hrl.harvard.edu