Corrective Pen

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Abstract

Involuntary tremors affect approximately 12 million people in the United States alone and are typically the result of three tremor-symptomatic conditions: Parkinson’s disease (PD), essential tremor (ET), and dystonia. Typically first observed in the distal part of the arm (in and around the hand), tremors significantly inhibit the writing abilities for much of the affected population. This report presents several designs for a self-contained writing instrument that aims to reduce the effects of involuntary tremors on handwriting via internal active and/or passive damping mechanisms. These designs include the use of integrated piezoelectric actuators to actively damp unwanted movement and a velocity-dependent magnetic fluid suspension to passively reduce excessive motion by the writing instrument. A novel method of emulating the effects of involuntary tremors in unaffected patients using a transcutaneous electrical nerve stimulation (TENS) device is also presented, with its effectiveness supported by preliminary results.

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The Need for Project

Involuntary tremors affect approximately 12 million people in the United States alone and are mainly caused by Parkinson's disease (PD), essential tremor (ET), and dystonia. Tremor onset is typically first observed in the hands and arms of the patient, and as many tremor-symptomatic diseases disproportionately affect people over fifty years of age, significantly impaired handwriting dramatically decreases their quality of life (Rep. 3.0). This results in a large potential user-base for a writing instrument able to reduce the effects of tremors on handwriting.

Project Objectives and Requirements

Design Objectives

The corrective writing instrument is designed to improve the legibility of handwriting, including print, cursive, and a combination, without the use of an external support structure attached to the patient's body or writing surface; however, the instrument may be tethered for power and control purposes, if applicable. The ideal usage case would allow a user to sit in a small chair at a doctor's office and inconspicuously fill out a form on a clipboard. This is challenging as distal arm tremors typically oscillate about 4Hz to 12Hz with magnitudes of the lower frequencies approaching 20mm (Rep. 3.1).

Design Requirements

As part of a three year NSF-funded grant, this project prioritizes comprehensive research on both existing technologies and thoughtful design concepts over the immediate selection of a final design and delivery of a completed prototype. These designs must not hinder the writing performance of a non-affected user while also permitting a tremor-affected person to write within one order of magnitude of the typical unaffected person, between 20-160 characters per minute.
Design Concepts

Generating different design concepts was a major focus of the project. The considered designs use a passive and/or active solution to damp vibrations. The passive concepts consider the use of various compliant materials in combination with highly sculpted ergonomics to inherently damp the system. The active concepts use electronics to sense and intelligently displace the writing instrument to significantly reduce unwanted movement.

A wide range of concepts have been considered with many quickly prototyped to assess their effectiveness (Rep. 4.1 – 4.2). Alpha-level prototypes have been created of a highly sculpted ergonomic grip, a pen with a proximally biased tip, and a pen suspended in viscoelastic foam with a rigid outer shell. While these designs did not provide substantial damping or effective response times, several promising concepts were derived from this initial testing. These concepts include a velocity-dependent magnetic fluid suspension to passively reduce excessive motion, a swivel design using damping grease between bearing surfaces, and a pen concentrically suspended by piezoelectric actuators inside an outer ergonomic housing.

Recommended Design Concept

Design Description

Several promising designs have been selected to prototype. As a reminder, this project is primarily research based with insights pertaining to novel and promising ways of damping tremors valued higher than prematurely selecting one final design. The directed problem statement simply states to "generate ideas and designs for a self-contained writing instrument that will improve writing performance and legibility in persons with involuntary hand tremors via active and/or passive damping." The leading three leading designs are discussed here (Rep. 5.0).

A magnetic pad design using iron filings suspended in a viscous fluid has been proposed. Velocity-dependent resistance is generated as a magnet attached to the pen moves over the surface of the pad, attracting the iron filings and sandwiching the paper between the pen tip and the pad surface. By changing the depth of the filing-containing reservoir, the viscosity of the fluid, the strength of the magnet, and the coefficient of friction between the iron filings and...
reservoir walls, the damping performance of the system can be optimized for a range of frequencies and displacements.

A separate design uses a writing utensil attached to a long horizontal rod that passes through two perpendicular rollers located in the top half of a circular base. These rollers spin as the rod passes between them and retard its motion as damping grease on the bearing surfaces is subjected to a velocity-dependent shear force. The upper half of the circular base also acts as a similarly-designed damper when the rod is rotated around the center axis of the base.

The third concept uses a pen concentrically suspended by piezoelectric actuators inside an ergonomic outer housing. Accelerometers located around the pen and in the outer housing are connected to a logic board to sense a tremor and calculate the appropriate response signal to negate the unwanted movement. This signal is sent to the actuators to deflect the writing instrument.

**Experimental Investigations**

A novel testing method using safe electrical muscle stimulation has been devised to emulate tremors in unaffected persons and has been used extensively to narrow ideas down to those proposed. Though the selected designs have not yet been prototyped, this testing procedure will be used to improve on the performance of each, eventually leading to the final design selection.

This testing method uses a transcutaneous electrical nerve stimulation (TENS) device to selectively stimulate certain muscles responsible for the tremors in affected patients. Various strength tremors may be emulated by changing the pulse width, duty cycle, current, or the electrically-conductive area through which the targeted muscles are stimulated (Rep. 6.1 – 6.2).

**Key Advantages of Recommended Concept**

Two of these concepts are passive, meaning they do not require an external power source and are completely mechanical. This results in lower manufacturing costs, maintenance, and recurring costs (e.g.—battery replacement). However, they may not be as effective as an active solution that would ideally damp only the unwanted movement caused by tremors.
**Financial Issues**

The active designs use very small actuators and accelerometers, requiring onboard logic and high-capacity batteries. The increased complexity of these designs results in estimated unit costs of $300-$700 when produced in annual volumes of ~1,000 units, depending on the design selected. Of note are the piezoelectric actuators which cost $235 each when purchased individually. The passive designs do not require any exotic materials or fabrication techniques and once mass-produced in annual volumes of ~1,000 units, the targeted per unit cost is $50-$150, again dependent on the selected design. It is anticipated that as a medical device, a patient’s insurance plan will offset the direct end-user price.

**Recommended Improvements**

Improvements to the selected designs will become apparent after testing begins. However, design simplifications to improve the ease and cost of manufacturing can be implemented, as can efforts to further reduce the overall physical volume of each design.