FoVi: A wearable focal vibration device provides adjustable precision vibration therapy

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BACKGROUND

Over the last decade, vibrations applied to the physical and rehabilitation medicine have been extensively investigated, including neurorehabilitation, a field where significant progress has been made in understanding both pathophysiology of the diseases and the influence of vibrational energy on the nervous system. Focal vibration (FV), a technique in which targeted vibration is applied to specific muscles or muscle groups, represents an innovative strategy to enhance balance and motor control across different neurological diseases. [1] FV indeed activates peripheral mechanoreceptors, leading to both short-term and long-term dynamic changes within somatosensory and motor systems, such that repeated applications may promote neuroplasticity with subsequent improvement in motor behavior. [1] Clinical and research evidences have shown satisfactory outcome of focal vibration as a useful tool in neurorehabilitation. [1]

However, many aspects of the commercial FV devices are unsatisfactory. These devices are operated through an open loop control, meaning that they may not deliver accurate vibrations. Another issue with these devices is that they lack a way to monitor or track the usage of the vibrational therapy, which is critically important for therapists to ensure that their patients are performing the correct dosage and length of treatment of FV. This causes a disconnection between the therapist and the patient when using these devices. Thus, new FV technology is needed to address the issues of current FV devices.

Our product FoVi (A wearable focal vibration device provides adjustable precision vibration therapy) is a low-cost wearable FV device which can adjust the intensity settings of vibration motors that can easily attach to the body and can provide direct feedback. The control and feedback system is accomplished through the use of a phone app. A web portal then allows for the therapist to monitor the usage, and remotely adjust the dosage based on rehabilitation progress.

METHODS/APPROACH/SOLUTIONS CONSIDERED

The user iterative design process described within the block-diagram presented in Figure 1 was used for this project. Multiple focus group studies including patients recovering from a stroke, physical therapist and occupational therapist and students were conducted to identify the needs and to develop the design specifications. During these different focus groups we demonstrated the current vibration devices and

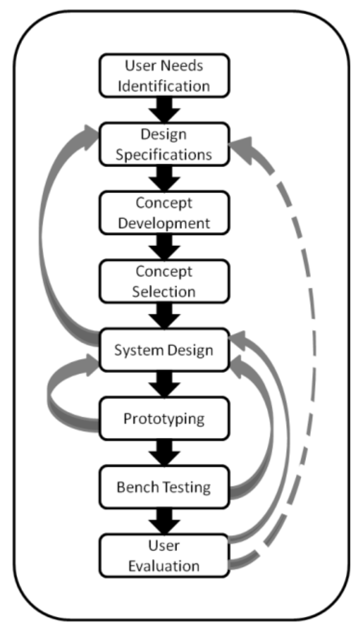

Fig. 1. Design process block-diagram.

asked for their feedback on the function, comfort, and wearability of the devices. This feedback guided our design of the new device.

A large problem with current vibration devices is the lack of feedback control. Clinicians want to monitor their patient's usage of the device and adjust dosage accordingly and current devices do not have that ability. Clinicians, patients, and caretakers agreed that ease of use was of high importance which included multiple ways for the device to function to meet the varying needs of patients and therapists. Patients also voiced that current devices were not user friendly in its wearability. The most functional device would be one that could easily be applied by the patient and would stay in place during normal activities of daily living.

We first considered whether the device should be controlled through the use of a remote, a control box, or a phone app. For the control box, the FV device would be wired, while for the remote and phone app, the FV device would be wireless. For the wired approach, the device had a central control box that is attached to the vibration motors via wires across the body. Control settings, i.e. off switch and intensity settings, for each motor are directly on the control box. We decided not to pursue the wired approach due to its lack of feedback control. The remote has the control settings for each motor and changes the settings via infrared (IR) light that is transmitted from the remote to the receivers on each motor. We also decided against the remote control because the remote would also lack the feedback control needed for an individual to accurately determine the FV dosage. The phone app wirelessly controls the motors via Bluetooth connection.

DESCRIPTION OF FINAL APPROACH AND DESIGN

Motor Design Description

Due to the inadequate control of the dosage of current FV devices, our device has the capability of adjusting the intensity of the vibration motors. Our device consists of four intensity settings: off, low, medium, and high. The device is equipped with a phone app, three vibration motors each supplied with its own accelerometer (STMicroelectronics© LSM9DS1), and a casing containing the following: a Bluetooth module (Adafruit Bluefruit LE UART Friend), a microcontroller (PJRC Teensy® 3.2), motor driver (Pololu© TB6612FNG), a battery (Adafruit® 1200 mAh Lithium Ion Battery), and a battery charger (Adafruit® LiPoly USB charger). The phone app allows the user to have direct control of each motor, i.e. turn off or on to a certain setting. The user can independently select either a low, medium, or high intensity setting for each vibration motor. The Bluetooth module allows for direct communication between the phone app and the microcontroller. The microcontroller controls the motor driver which then in turn manipulates the vibration motors. Each motor has its own accelerometer that reads the acceleration caused by the vibration for feedback control.

The battery level of each motor is determined by an LED light on the motor, i.e. red light for low battery and green light for high battery. The cell phone app displays the intensity level for each motor from the data received from the Bluetooth module via BLE, i.e. off, low intensity, medium intensity, and high intensity. The Bluetooth module receives the data from the microcontroller via UART and also transmits these data via BLE to the phone app for feedback control. The microcontroller controls the vibration motors which then in turn activates the vibration motors. Each vibration motor is equipped with an accelerometer,

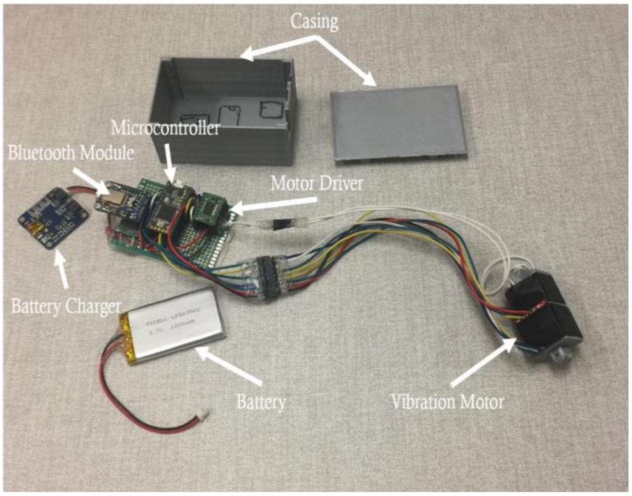

Fig. 2. Product photo.

which reads acceleration data from the vibration motors. These readings are sent back to the microcontroller via SPI (Figure 2). The motors are separated from the electronics and from each other to ensure that miniscule interference occurs between the motors and the electronics and also between each motor for greater feedback control.

Feedback Control

The phone app displays the current status of intensity for each motor. When the user changes the intensity levels of the vibration motors, the information is sent from the app to the Bluetooth module via BLE. The data is then delivered to the microcontroller via UART which then activates the motor driver. The motor drivers then alter the intensity levels of the vibration motors to the specified intensity level. Acceleration readings are collected from the accelerometer on each vibration motor and transferred to the microcontroller via SPI. The readings are then conveyed to the Bluetooth module via UART and then are transmitted to the phone app via BLE. Finally, the phone app displays the updated status of the intensity levels of each motor (Figure 3).

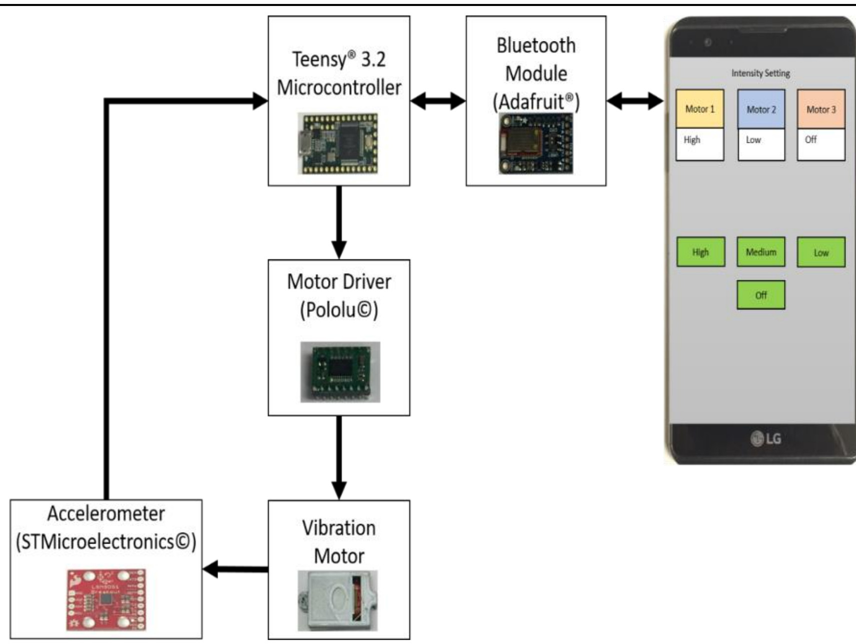

Fig. 3. Feedback control diagram.

Current Iteration

The current phone app we are using for control of our device and for direct feedback is Nordic® nRF Toolbox mobile app. When the device is off, the display reads 0g, where g is the acceleration of the device relative to gravity, which is the acceleration reading from the accelerometer. The following is displayed on the app for the low, medium, and high intensity settings, respectively: 2g, 5g, and 9g, where the first setting is for low, second setting is for medium, and third setting is for high (Figure 4). Furthermore, we are using only one motor for control through Bluetooth connection. However, a wired connection is required for the motor and accelerometer to connect to the Bluetooth module, microcontroller, and motor driver.

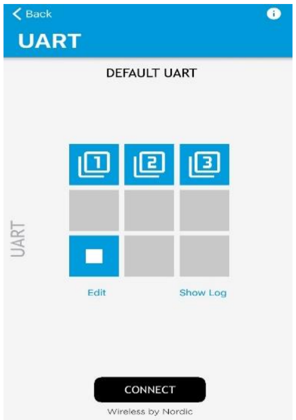

Fig. 4. Current Phone app control.

Vibration Sleeve

Since the comfort level and user friendliness of the current FV devices is inadequate, we designed an adjustable sleeve to increase comfort and user friendliness. The vibration sleeve is comprised of vibration modules placed in strategic locations to provide vibration therapy to each individual muscle. The vibration modules are vibration motors placed in between an air bladder and a rubber pad (Figure 5). The rubber pad distributes the load from the motor more uniformly and provides added comfort for the user. When the air bladder is deflated the user experiences the maximum vibrational forces from the motor. When the air bladder is inflated it provides a damping effect to the motor. The user can control the amount of air pressure in each vibration module independently with the valve manifold, providing each muscle with the appropriate vibrational strength. The user can also adjust each vibration modules motor speed independently via the electronics control, effectively varying the frequency. By allowing both the vibrational strength and frequency to be independently adjusted for each module, the user will be able to administer the appropriate dosage of vibration therapy in a controlled manner. The vibration sleeve is an accessory to aid the user in correct placement of the vibration device. This ensures that vibration will be applied to the designated muscles prescribed by the therapist (Figure 6).

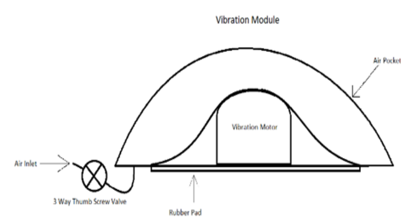

Fig. 5. Vibration module.

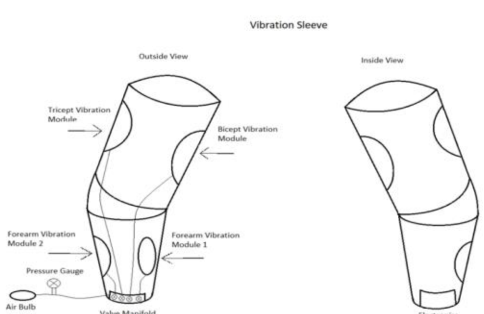

Fig. 6. Vibration Sleeve.

OUTCOME

We wanted to create a device that therapists would feel comfortable using and prescribing to their patients knowing that the vibration dosage would be consistent and could be monitored. This device also needed to be accessible and functional to patients. The design for FoVi was guided by feedback from multiple focus groups. After presentation and demonstration of current devices on the market, patient and therapist feedback was compiled. Many aspects of the commercial devices were found to be dissimilar and unsatisfactory: i) lack of accurate vibration, ii) insufficient dosage feedback for user, iii) No usage or dosage tracking and monitoring, iv) Discomfort,v) Difficulty donning and doffing vi) Inadequate control of dosage, vii) wearability, i.e. not wireless and difficult to use when performing other tasks while FV is delivered, and viii) lack of communication protocol between patients and therapists. These focus groups will also be evaluating our device for further improvements to our design.

COST

Prototype Costs	
3D print Casing	$15
Accelerometer	$16
Bluetooth Module	$17.50
Motor Driver	$3
Motor	$1
Battery	$10
Battery Charger	$12.50
Proto board	$1
Total	$76

SIGNIFICANCE

FoVi was designed so that it could be versatile as both a rehabilitative and an assistive device to deliver precision vibration therapy. Clinically, focal vibration can be used to increase range of motion, decrease pain, and decrease spasticity [2]. Focal vibration can also be used as an assistive device to aid in postural control and cue reminders through proprioceptive input which increases balance and stability and decreases fall risks [3]. FoVi delivers vibrational therapy where a therapist can monitor the usage and remotely adjust dosage of the vibration. FoVi is functional and can be worn during normal activities. This device will also help decrease pain and increase motion in a patient friendly manner. Both patients and clinicians can monitor and adjust the vibration through direct feedback control. The existing devices do not deliver accurate vibrations to target muscles. FoVi delivers precise vibrations through the use of a closed loop control. Thus, our final design has the potential to be an assistive device as part of a home treatment plan. FoVi can be used in the clinical, home, or community setting.

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