Passive Nonlinear Energy Sink for Pathological Tremor Reduction

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Summary. Medications used to reduce the pathological tremor causes severe side effects which affects the life quality of the patients. A mechanical solution using nonlinear passive controllers is suggested to reduce the tremor. A light weight non-smooth nonlinear energy sink (NES) attached to the forearm of a modeled upper limb system was able to reduce the angular motions, of different parts of the upper limbs, after a short period of time.

Introduction

Tremor is an involuntary oscillatory movement of a body part triggered by alternating simultaneous antagonistic muscles contractions. It is associated with neurological disorders which lead to pathological tremor, like the Parkinson and essential tremors. Neurologically disordered patients suffer from a frustrating involuntary tremor which prevents the patients from achieving their daily life tasks and can cause social isolation. There is still no cure for the pathological tremor, and the effect of the used medication and surgical treatments are temporary. In addition, the treatments can cause severe side effects specially in case of non-responsiveness or medication failure.

Research interest was recently shifted to find a mechanical solution for reducing the vibration tremor energy at the upper limbs of the patient. The mechanical absorber is suggested to counter-act the tremor and to compensate the failure of the muscles in performing accurate motor movements. A passive controller, using a non-smooth nonlinear energy sink (NES) [1], is suggested in this paper to reduce the involuntary tremor of a modeled upper limb system.

Modeled system

The upper limbs of the human is modeled dynamically to reflect the tremulous motion. The response of the system is used to design the physical parameters of the nonlinear vibration absorber placed at the forearm segment. The performance of the suggested controller is examined by comparing the response of the system before and after the addition of the NES.

Upper limbs

The upper limb is modeled as a two degrees-of-freedom (DOF) system oscillating in the vertical plane as shown in shown in Figure 1. The upper limbs can be modeled as two rigid links, the upper-arm as one segment, and the forearm and hand together as a separated segment [2]. The links are represented as massless rods of length (l) with a concentrated mass (m) placed at the position of the centroid (r), where the indices 1 and 2 refer to the upper arm and forearm, respectively. The modeled system allows the flexion-extension planar motion at the shoulder and elbow joints, where θ_1 and θ_2 are the angular displacement responses at these joints, respectively.

The musculoskeletal modeling of the upper limb is reached by the addition of the shoulder, elbow and Biceps brachii muscles to the skeletal system. The passive elements of the muscles are the stiffness (k) and damper (c), such that the indices 1, 2 and 3 corresponds to the shoulder, elbow and Bicesps brachii. The upper limb system is excited the active torques generated by the muscles. The signals of the muscles can be measured by the Electromyography (EMG), which can be used to detect the operational frequency of the muscle, and the amplitude of the signal at this frequency. The inertial measurement unit (IMU) can be used to determine the acceleration and angular velocity ranges, which needs to be reached by the responses of the modeled upper limb system.

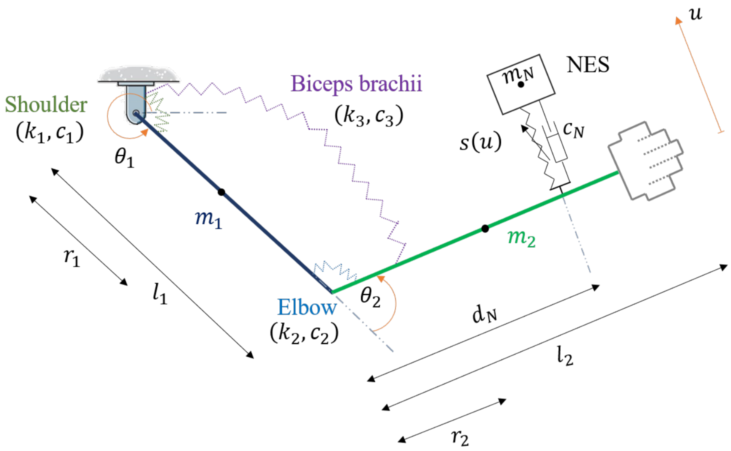

Figure 1: Dynamical modeling of the upper limb in the vertical plane with a NES

Nonlinear absorber

The well modeled upper limb system leads to an accurate design of the NES parameters. The NES has a light weight mass (m_N), placed at the forearm segment at a distance (d_N) away from the elbow joint. The displacement response of the NES (u) is acting in the vertical place, in a direction perpendicular to the forearm segment. The NES oscillating in this direction, is designed to absorb the flexion-extension angular displacement of the upper limbs during its oscillation in the vertical plane. A non-smooth piece-wise linear function is chosen for the NES since it can create, a better controllability effects, when attached to a system affected by the gravitational field, than the cubic restoring function [3]. The piece-wise linear function is characterized by the stiffness of the NES (k_N) and the clearance ($2d$).The damping of the NES is c_N.

Complexification of the system

The nonlinear equation representing the motion of the global system (upper limbs with NES) is derived using Euler-Lagrange formula. The equations are linearized using Taylor series multivariable linearization method in terms of θ_1 and θ_2, while preserving the nonlinearity of the NES (u).

The complex variables of Manevitch [4], are applied to the partially linearized equations of motion transformed to the modal coordinates. The multiple scale method [5] is used to treat the system at different timescales, low timescale $\tau_0 = t$ and fast timescale $\tau_j = \epsilon^j t$, such that t is the time, ϵ=$\frac{m_1}{m_N}$ and $j = \{1, 2\}$. The averaged equation is obtained by applying a truncated Fourier series (constant terms and first harmonics) [6] to the equations transformed to the modal coordinates.

Results and discussion

The response of the system is analyzed in different time scales. The slow invariant manifold (SIM) and characteristic points of the system are obtained from the analytical study. The numerical response of the system shows to follow the SIM obtained analytically. The parameters of the NES are designed such that resonance occurs at the fundamental frequency of the main system. Figure 2 shows the angular displacement response at the shoulder and elbow joints before and after the addition of the NES, for different m_N. The controllability response of the NES is faster when its mass is higher. The NES of 20.7 g reduces the response of the system after 180 s. The mass of the NES can still be increased to obtain a faster performance.

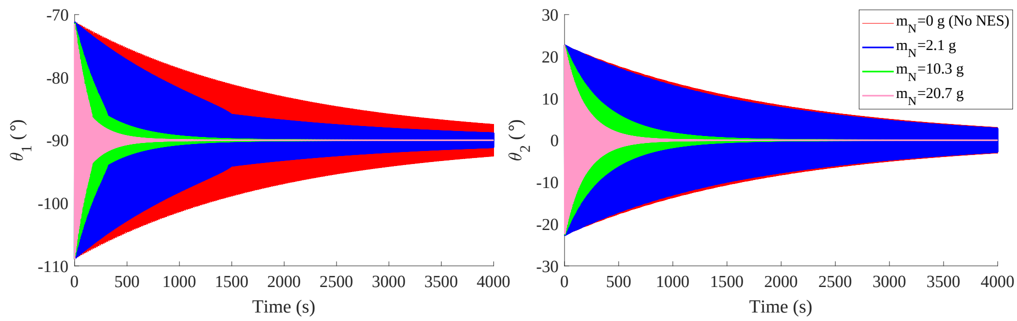

Figure 2: Angular displacement signals at the shoulder and elbow joints simulated numerically with and without NES for different m_N

Conclusions

The NES with piece-wise linear function is effective in reducing the involuntary tremor gravitational energy transmitted to the upper limbs due to the muscles contraction. The NES can be designed in the form of a non-invasive device to help people with pathological tremor.

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