A passive nonlinear absorber for controlling pathological tremors of human arm

Sarah Gebai[1], Alireza Ture Savadkoohi[1], Claude-Henri Lamarque[1]

[1]Univ Lyon, ENTPE, Ecole Centrale de Lyon, CNRS, LTDS, UMR5513, 69518 Vaulx-en-Velin, France
{sarah.souheilgebai, alireza.turesavadkoohi, claude-henri.lamarque}@entpe.fr

Abstract

Patients with Pathological tremor at their upper limbs suffer from the involuntary tremor which prevents them from doing their daily tasks. The available medical treatments for this disease can reduce the symptoms of the tremor for a short period of time, but doesn't cure the disease. Knowing that used medications and surgical treatments causes severe side effects, some patients reject receiving such treatments. This paper proposed the usage of the nonlinear type of passive mechanical vibrations absorbers to reduce the oscillations in the upper limbs for patients with essential tremor. The nonlinear type of passive absorbers is considered as a new technology in this field, which is expected to compete with the existing devices used to control the tremor.

1 Introduction

Neurologically disordered patients suffer from pathological tremor which can lead an uncontrollable level of shaking in the affected parts of the body. Until now, involuntary tremor have no cure because of its unknown pathology. The effect of the existing medications and surgical treatments, used to deal with this disease, are temporary and can cause severe side effects that deteriorate the life quality of those patients.

Involuntary tremors are characterized by different frequency ranges. The frequency ranges for the rest tremor (RT), postural tremor (PT), and kinetic tremor (KT), are respectively, 3-7 Hz [1], 5-12 Hz [1], and 3-10 Hz [2]. Parkinson disease is related to the RT and PT. The essential tremor (ET) is a bilateral of PT and KT. The mechanical vibration absorber is usually used to reduce the undesired vibrations. A similar solution can be suggested to reduce the involuntary tremor at the upper limbs of the patients. Vibration absorber can be designed to target the high amplitudes within the frequency bandwidth of the tremor, aiming to maintain the stability of the hands while performing the daily tasks. The passive type of vibration absorbers have simple design and required no power to operate. Passive absorbers could be designed in the form of bracelet using safe elements which has no impact on the health of the patient.

The usage of passive linear absorber was initially proposed by Hashemi et al. [3]. It was fabricated in the form of cantilever beam tuned at resonance, and tested on a two-link system oscillating in the horizontal plane to reflect the RT of an upper limb supported on a table. The absorber was effective in reducing the flexion-extension motion at the joints. Rudraraju and Nguyen [4] fabricated two linear tuned absorbers, placed symmetrically at the top and bottom of the hand. This device was tested on a mannequin hand to reduce the motion in the horizontal direction. Then, examined on the patient with ET, by tracing the pre-drawn line on a whiteboard. Gebai [5] excited an experimental arm, by a shaker, using the measured tremor signals of the PT in patient with ET. Optimized passive linear absorbers, modeled as cantilevered beams, shows to reduce the flexion-extension angular displacement amplitude at the joint.

The efficiency of passive linear absorbers is highly affected by the changes in the excitation frequency. In order to avoid this problem, and to have a device efficient over a larger frequency bandwidth, True Savadkoohi et al. [6] proposes the usage of passive nonlinear absorbers to control the tremor. In this work, we modified the previously mentioned work, by changing the type of the used nonlinear absorber which is expected to deliver a better preformance. The necessary equations needed to design the absorber are derived and solved, where the efficiency of the absorber is analysed.

2 Dynamic modeling of the system

The upper limbs is designed as a dynamical system which is oscillating due to the excitation moment generated by the activity of the muscles causing the tremor. This description is based on the academic model provided by Jackson [7]. The angular displacement response of the upper limbs, calculated with respect to a chosen postural position, is represented as $\Delta\theta$.

The nonlinear absorber is designed and attached to the modeled upper limbs system. The equations of motion of the global system is derived using the Euler-Lagrange formula, and solved. The relative translation displacement of the nonlinear absorber, with respect to its initial displacement due to the postural position, is represented by Δu.

In this work, the sinusoidal moment, of an arbitrary amplitude, is applied to excite the system at resonance. An absorber of a very small mass is used to test the ability of nonlinear absorbers in reducing amplitude of the system. This academic example allows to validate the modeled system. It is considered as the first step needed for the designation of the proposed nonlinear absorber. Numerical simulation is done to solve the equations of the system, using $ode45$ and to analyze its behavior.

3 Results and discussion

The physical parameters of the nonlinear absorber are designed to reduce the angular displacement amplitude of the system using the multiple scale method [8]. These parameters are evaluated and used to simulate the response of the global system. The obtained results are shown in Figure 1. The duration of the simulation is 7×10^{-3}s, where a part of the signal is extracted to provide a clear view of the response. Figure 1a shows the response of the upper limbs before (blue line) and after (black line) the addition of the nonlinear absorber. As showsn, the absorber causes very high reduction in the amplitude of the system, leading to a quasi-periodic response. Simultaneously, the nonlinear absorber undergoes persisting bifurcation as shown in Figure 1b.

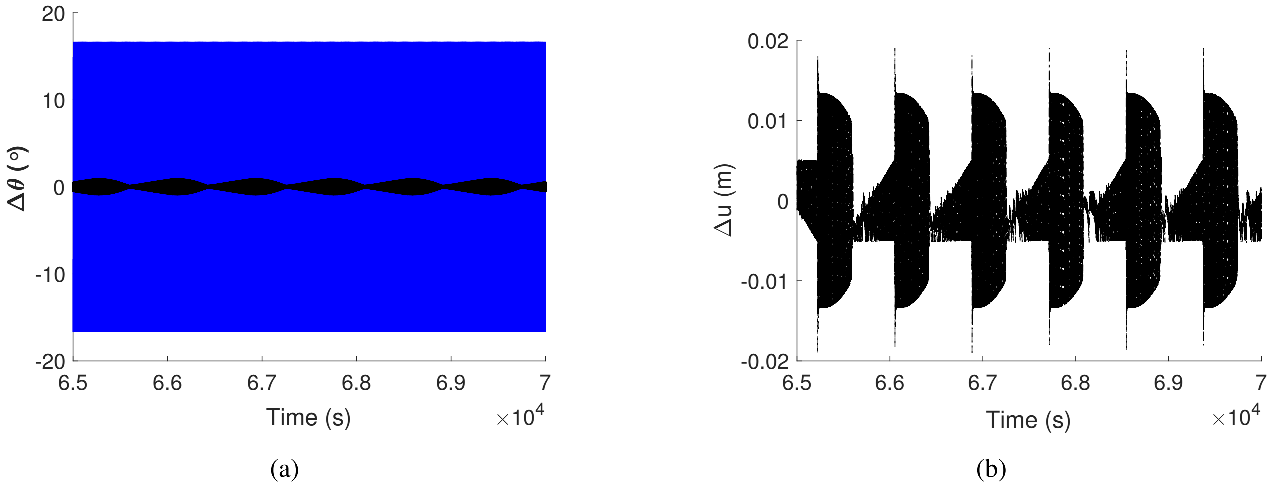

Figure 1: (a) Response of the modeled upper limb system (blue line without absorber and black like with absorber); (b) Response of the nonlinear absorber

4 Conclusions

The elements needed to design the nonlinear absorber are prepared and validated. The nonlinear absorber shows to be efficient in reducing the displacement amplitude of the modeled structure. A more realistic response of the upper limbs should be obtained by a good estimation of the characteristics of the excitation signal. Then, the parameters of the nonlinear absorber can be well chosen, such that the displacement amplitude of the upper limbs doesn't exceed a specific threshold, while the absorber oscillates within a reasonable amplitude range. Finally, a suitable device can be sized and fabricated.

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