IMPLEMENTATION OF A NEGATIVE STIFFNESS MECHANISM FOR VARIABLE STIFFNESS ROBOTS

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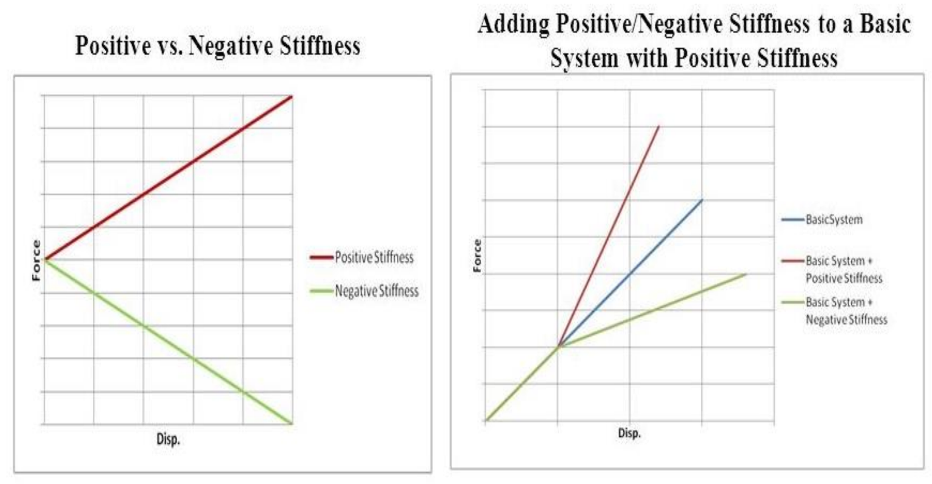
Abstract

Negative stiffness is a naturally occurring phenomenon which takes place during buckling of beams, that may be exploited to achieve extreme stiffness and damping properties for variable stiffness actuators.
This project aims at implementation of a negative stiffness mechanism to be utilized as a part of variable stiffness actuators in robotics. This project gives a guide studying simple models that lead to negative stiffness, constructing several prototypes of such mechanisms by using rapid prototyping techniques and experimentally verifying the range of negative stiffness achieved by each prototype.

Motivation

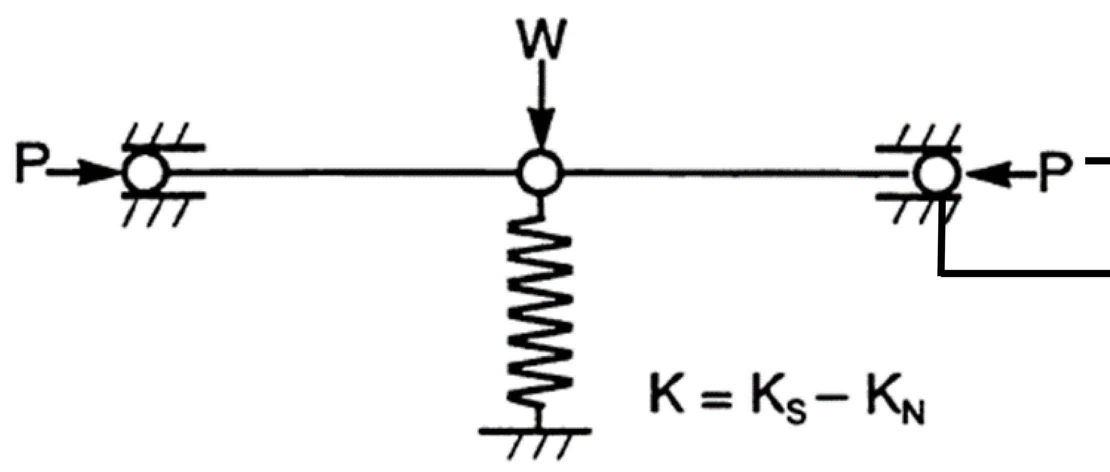


(Attary and Symans, 2012)

- Controlling stiffness using a mechanical mechanism that provides variable stiffness which is a more convenient, energy and cost efficient way to generate haptic interfaces.
- Using the negative stiffness characteristics, setting the lowest stiffness arbitrarily close to zero while making very high stiffness values also achievable (Yalcin et al., 2013).

Experimental Set-up

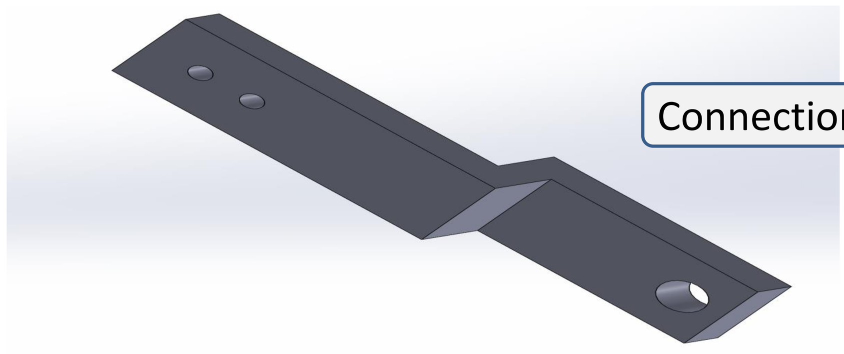
The Lego NXT system is attached to the metal sheet with connection parts sketched in Solidworks. Stiffness of the metal sheet is controlled, measured.



(Vibration Isolation Using Acoustic Band Gaps and Negative Stiffness, 2017)

Firgelli L12 LEGO NXT 50mm linear actuator

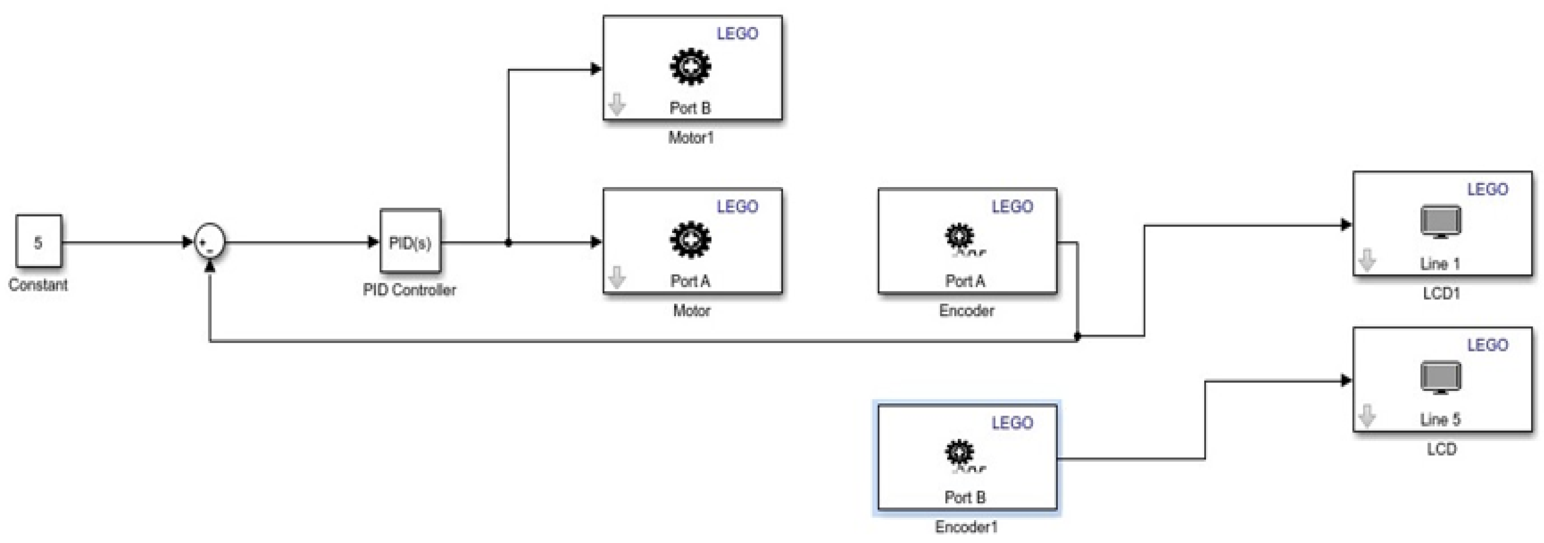
Firgelli L12 LEGO NXT 50mm linear actuators



Connection part

Controller

Linear motors should be coordinated, that is why it is necessary to use PID control.



PID control is a mechanism that provides the error to the user and makes the addition with the error and the input in order to make result value as close as possible to the desired value. It also uses the result value to make the second motor coordinated with the first motor.

Managing the two actuators moving at the same time (actually first motor is before the second one because of it following the second one and it gets the input from the first motor so this is a normal behavior) with the same value.

Case Studies

With different weights, different values of stiffness is measured by using the formula;

Stiffness   Stress   Mass

$$k = \frac{\pi^2 \sigma m}{L^2 \rho}$$

Length   Tissue Density

(The National Center for Voice and Speech - Tutorials)

By using the formula ***Force = Stress * Area***, the stress is found and substituted to the equation above. As a result, different stiffness values are obtained.

References

Yalcin M., Uzunoglu B., Altintepe E., Patoglu V. (2013). VNSA: Variable Negative Stiffness Actuation based on Nonlinear Deflection Characteristics of Buckling Beams. In IEEE/RSJ International Conference on Intelligent Robots and Systems.

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Mochida Y., Naohiro K., Ilanko S. (2014). Base Isolator of Vertical Seismic Vibration Using a Negative Stiffness Mechanism

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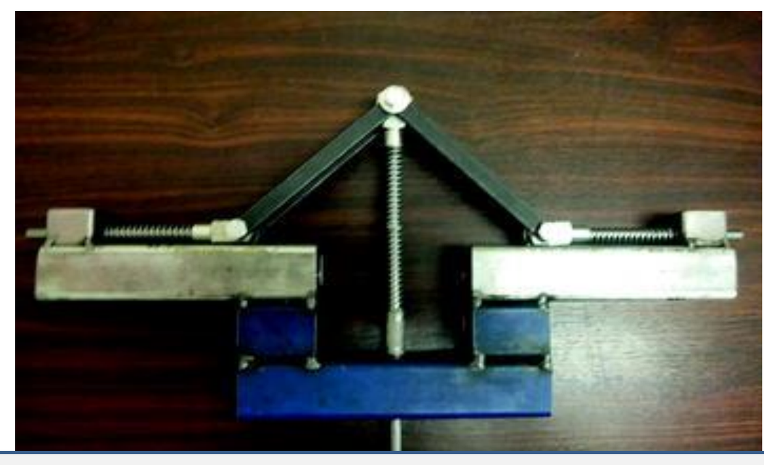
Results and Discussion

For other applications, larger traverse deflections can be achieved by increasing the length of the buckling beams that can be achieved by increasing the surface area for the device. With a different kind of an actuator with very low stiffness can be implemented utilizing the negative stiffness of buckling beams.
This negative stiffness mechanism can be used in other scientific researches such as virtual reality researches and seismic isolation systems.

Prototype of virtual reality haptic gloves (Teslasuit - full body haptic VR suit)



Prototype of a base isolator of vertical seismic vibration (Mochida et al., 2014)

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