BIOMECHATRONICS

A
PROJECT
ON
ARTIFICIAL MCKIBBEN MUSCLE

SUBMITTED TO

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OBJECTIVE

Model the attributes of the McKibben muscle as explored in the referenced papers and construct a Simulink model with two links to replicate the human hand form. The objective is to simulate the torque generated at the joints when lifting a mass "M." Subsequently, integrate the McKibben artificial muscle into the model to demonstrate a reduction in torque at the joints while lifting the same mass.

SUMMARY OF THE PAPERS

The research papers that we went through have developed a dynamic model for the two-muscle system that is based on the component's physical attributes as opposed to employing coefficients that have been found through experimentation. This makes it possible to simulate and forecast using the model before building the actual muscles.

In order to simulate the momentary response that occurs when the muscles are compressed or expanded, the model includes valve dynamics. To effectively mimic the actual physical system, this is crucial.

Paper 1 (Tondu and Lopez 1997):

Modeling and control of McKibben artificial muscle enhanced with echo state networks Kexin Xing a,n , Yongji Wang b , Quanmin Zhu c , Hanying Zhou b

Presents an Echo State Network (ESN) model to capture the nonlinear dynamics of a McKibben muscle An adaptive ESN control scheme with online learning is proposed for trajectory tracking of the muscle Simulation and experiments show improved performance over classical PID control The ESN approach avoids complex physical modeling and provides robustness to uncertainties

Paper 2 (Xing et al. 2012):

Embedded bifuricaations into pneumatic artificial muscle

N.Akashi, Y.Kuniyoshi, T.Jo, M.Nishida, R. Sakurai,Y.Wakao, K.Nakajima

Proposes a static model for McKibben muscle force based on energy conservation and experimental tension-length data Static model accounts for elastic energy loss and friction losses inside muscle Discusses static properties like force-length relationship and similarities to biological muscle.

Paper 3 (Tondu 1997):

The McKibben muscle and its use in actuating robot-arms showing similarities with human arm behavior Bertrand Tondu University of Toulouse Pierre Lopez

Discusses use of McKibben muscles to actuate robot arms and similarities with human arm function Notes advantages like light weight, compliance, high power/weight ratio Describes early applications in powered orthotics and ongoing use for human-friendly robotics Makes comparison to biological muscle properties throughout.

Paper 4: Measurements and Modelling of McKibben Pneumatic Artificial Muscles:

Ching-Ping Chou and Blake Hannaford

The paper presents testing and modeling of McKibben pneumatic muscles, which contract axially when pressurized due to a surrounding braided shell. Experiments reveal velocity-insensitive hysteretic properties. A static model treating the muscle as a variable-stiffness spring is developed along with lumped parameter models of test pneumatic circuits. Comparisons to biological muscle highlight similarities in force production but limitations in dynamics and efficiency of the pneumatic systems. Further improvements to match muscle performance are needed.

Paper 5: Modelling of the McKibben artificial muscle: A review

Bertrand Tondu

The paper reviews modelling of McKibben pneumatic muscles, which contract lengthwise when pressurized due to a braided shell. An ideal cylindrical force model is derived, relating force to pressure and geometry. Complex effects like friction, hysteresis and muscle tip shapes make static modelling difficult. Dynamic modelling incorporates viscosity and velocity dependence, enabling muscle-like behaviour. Interactions between elastomer physics and textile physics in the soft materials pose modelling challenges, thus no definitive McKibben model exists capturing all static and dynamic complexity.

REPLICATIONS TAKEN FORM PAPERS

From the conclusion section of first paper we have taken the Parameters of the Pneumatic muscle. As, they have followed the Echo state networks model which gave them a pretty good results of non-linear characteristics of pneumatic muscle. So, we have replicated the parameter values in the Simulink model of our McKibben muscle.

From the sixth section of the fourth paper, we found the differentiation between the human biological muscle and artificial muscle developed by three different materials. From that we got to know the artificial muscle can handle more tension and stiffness along side with a higher dynamic range.

MODELLING THE HUMAN HAND AS A TWO-LINK MANIPULATOR

In this step, we defined a kinematic model that represents the human hand as a two-link manipulator. The two links correspond to the forearm and the hand.

Adding a Mass at One End:

we attached a mass at one end of the manipulator. To model this we considered the

dynamics of the system, including the mass, its location, and any additional forces or torques involved.

Simulating the Model in Simulink:

Once we have the kinematic and dynamic model, we use Simulink to simulate the system over time. Simulink has provided blocks for modelling mechanical systems, and we did set up a simulation that calculates the motion and torques at the joints over the simulation time.

Observing Torque Generated at the Joints:

During the simulation, we monitored and visualised the torque generated at the joints. This information is crucial for understanding the effort required at each joint to move the system.

$\tau2=I2\theta2+m\cdot g\cdot l2\cdot \cos(\theta1+\theta2)$(at elbow)

$\tau1=I1\theta1+m\cdot g\cdot l1\cdot \cos(\theta1+\theta2)$(at shoulder)

- $\tau2$=Torque at the elbow joint.
- I2=Moment of inertia of the second link (elbow).
- $\theta2$=Angular acceleration of Joint 2 (elbow).
- m=Mass at the end of the second link.
- g= Acceleration due to gravity.
- l2: Length of the second link (elbow).
- $\theta1$= Angular position of Joint 1 (shoulder).
- $\theta2$=Angular position of Joint 2 (elbow).

We used the above formula to calculate the torque at the elbow. So as this we can calculate the torque produced at the shoulder as well.

Below are the simulink framework and the generated graphical torque outputs:

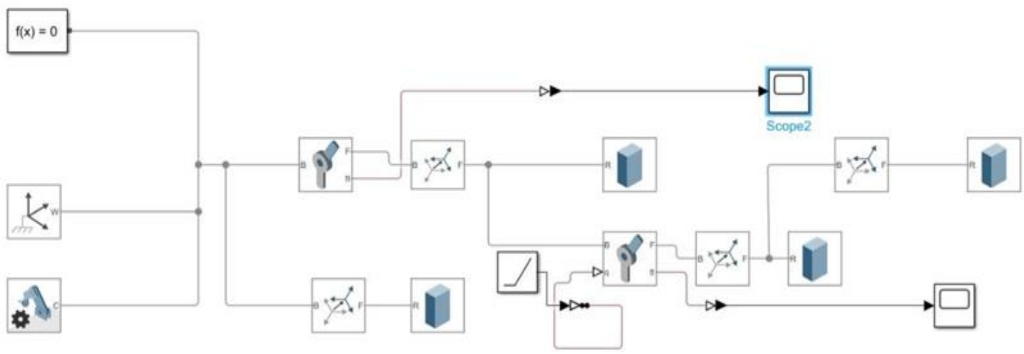

Fig 1: Sumilink framework of human arm

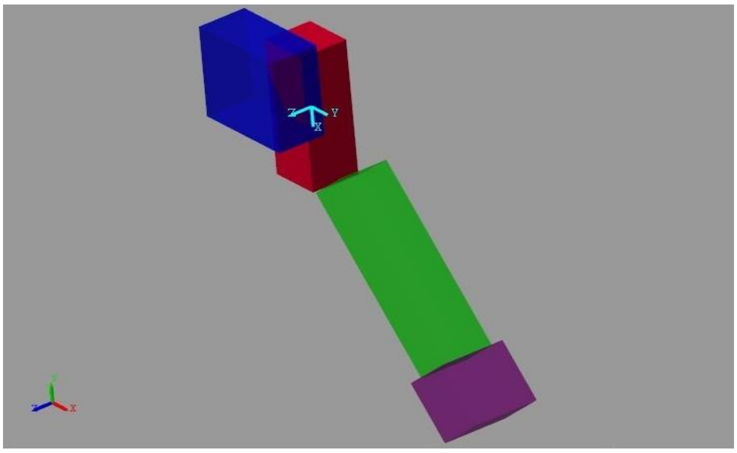

Fig 2: 3D model of links at home position with mass m at end effector

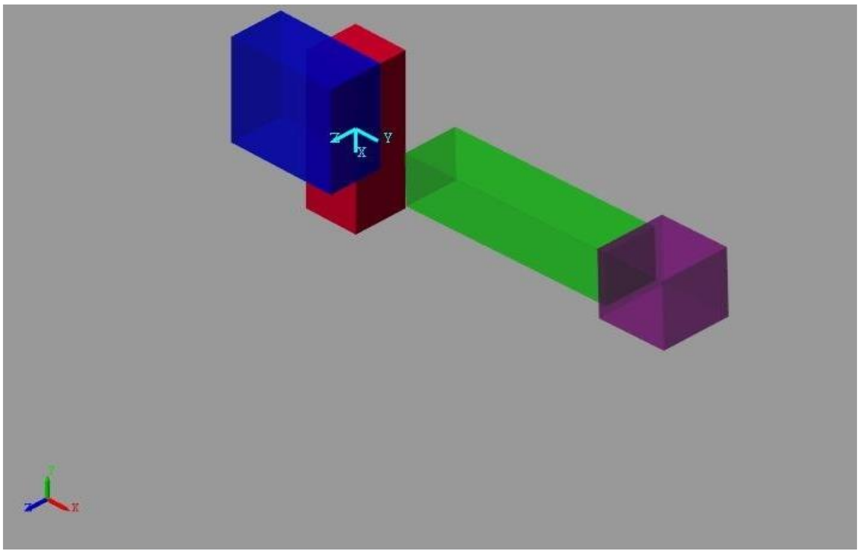

Fig 3: 3D model of link then mass m at end effector is lifted

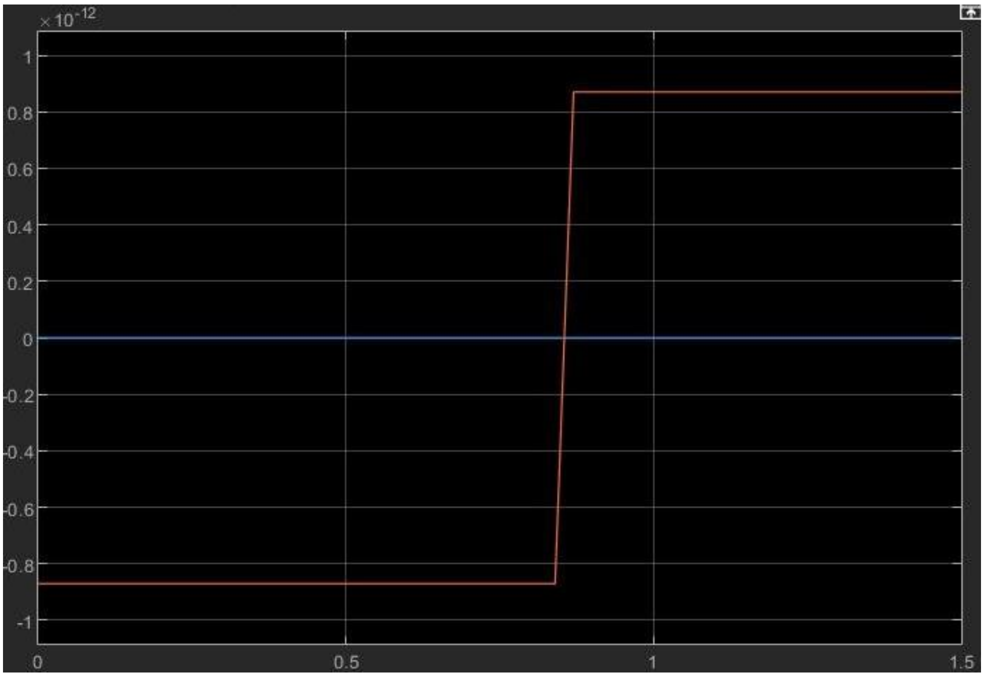

Fig 4: Torque generated at the elbow

While the mass M is being raised, the torque in the elbow increases and stabilizes at a constant value by the end of the simulation.

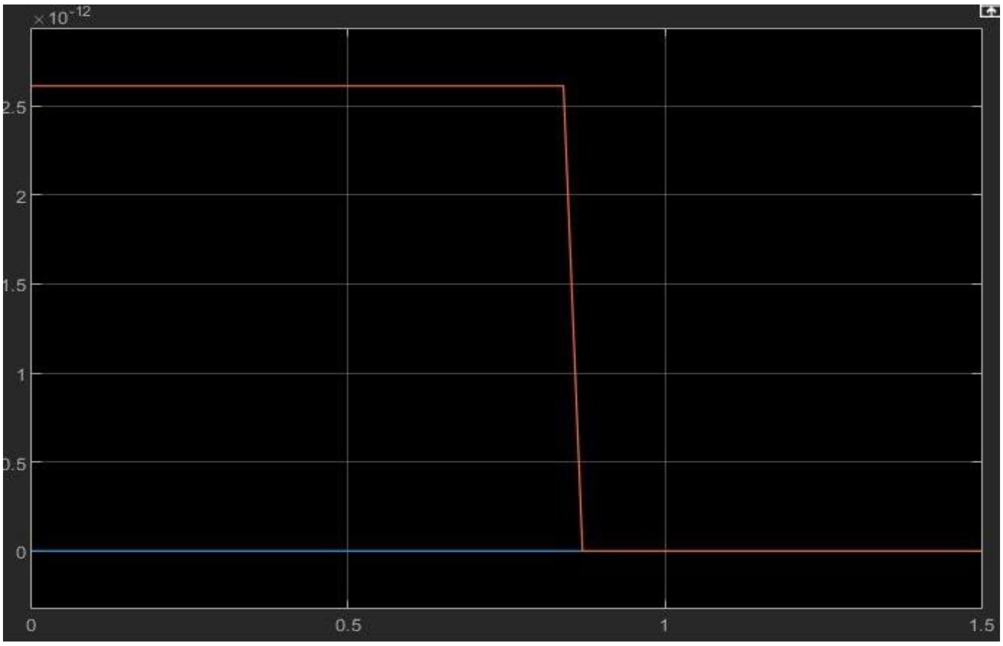

Fig 5: Torque generated at shoulder joint

The torque at the shoulder joint diminishes to zero during the process of lifting a weight, starting from an initial torque and gradually decreasing.

After developing the mechanical design we started implementing pneumatic air muscle in simulink.

Define the Mechanical System:

Created a Simulink model and Represented the mechanical components of the system using appropriate blocks. For an air muscle we used Simscape Multibody blocks.

Modelling the Pneumatic System:

Added blocks to model the pneumatic system, including the air muscle. Considered using Simscape Fluids blocks to represent the air flow, pressure, and the behaviour of the muscle.

Connecting Mechanical and Pneumatic Components:

Connected the mechanical components to the pneumatic components appropriately in our model.

Specifying Parameters:

We had Set parameters such as muscle length, initial pressure, and other relevant physical properties.

Simulate the Model:

We Ran simulations to observe the behaviour of the system over time.

Analysing Results:

Analysed the simulation results to understand the performance of the pneumatic air muscle. This might involve studying muscle contraction, force generation, or other relevant metrics.

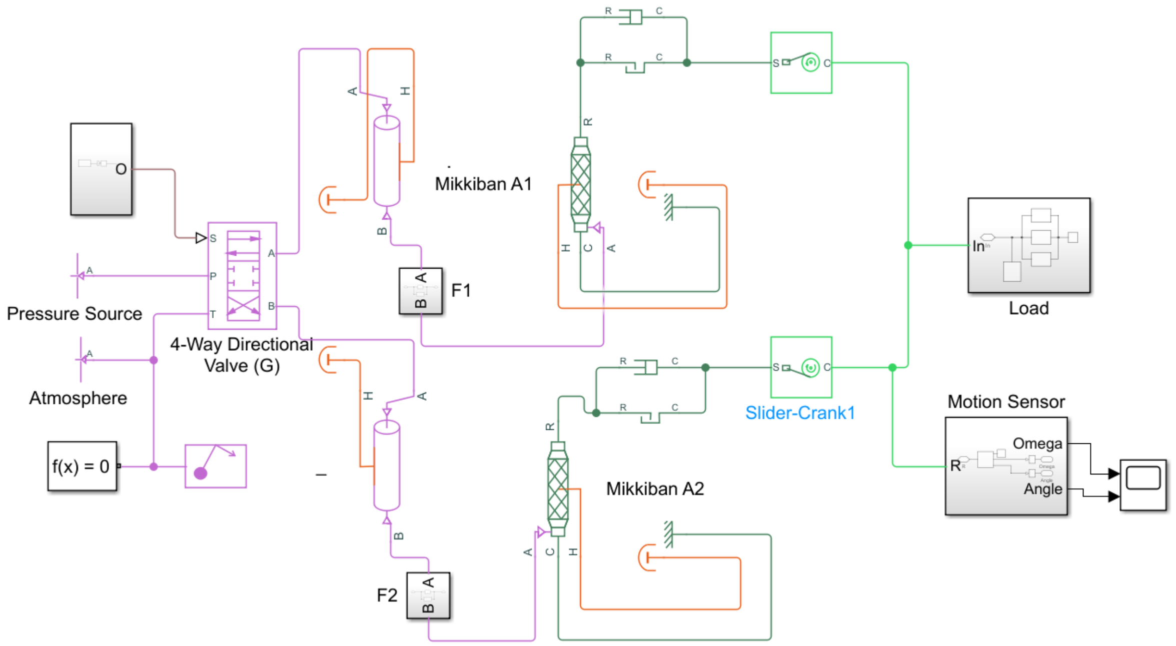

Fig 6: Mckibben muscle model in Simscape

We are employing a pneumatic McKibben artificial muscle, actuated by a 4-way solenoid valve regulated by an input voltage. The valve adjusts pressure between a supply and atmospheric pressure to inflate and deflate the muscle, aligning with documented properties such as force, length, and velocity. To harness the force and motion of the contracting muscle, we've linked it to a slider-crank mechanism with an attached load. Muscle activation occurs through the solenoid valve input, connected to a translation hard stop and translation damper to restrict motion and safeguard components from pressure-related damage. This setup interfaces with the slider-crank, converting linear muscle motion into rotational motion to displace the load. We capture various outputs, including load angular position and velocity, during muscle actuation over time. The muscle parameters and slider-crank offer a platform for testing control strategies for pneumatic McKibben muscles that replicate bio-inspired motions.

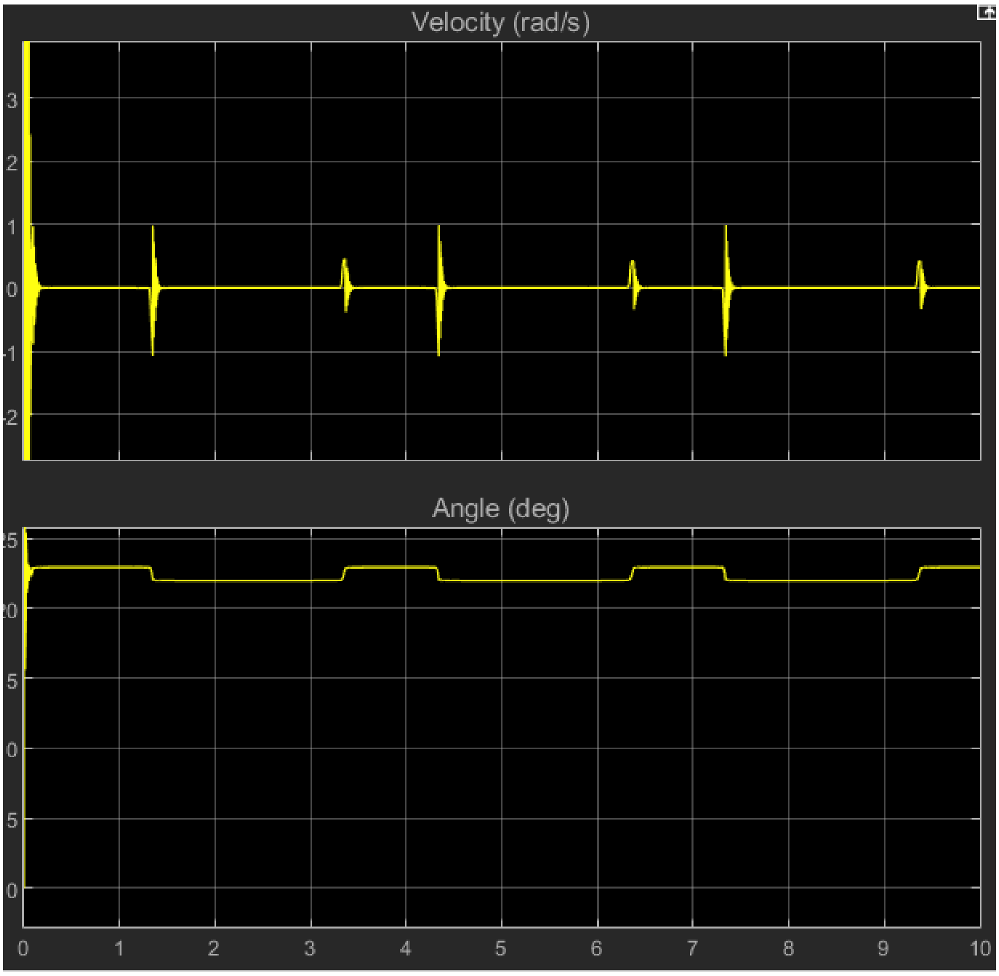

Fig 7: Results of velocity vs time and Angle vs time

From these depict the air muscle characteristics acting on specific load and angle of velocity.