Passive Anti-Vibration Utensil

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1 Background

Approximately 7 million people in the U.S. suffer from Essential Tremor, a movement disorder most often involving tremors of the hands, wrist, and arms. An additional one million people suffer from Parkinson's Disease which can result in hand tremors in addition to the numerous other symptoms. Roughly sixty-five percent of these patients have tremors severe enough to affect normal daily activities like eating. For many people with these severe hand tremors, using a spoon, or in many cases even a fork, can result in embarrassing spills and very little food actually making it to their mouths. A solution is needed to allow these patients to feed themselves comfortably without spilling.

Recently the company Liftware came out with a utensil that solves this problem electronically. The Liftware utensil senses the motion of the hand and then uses motors to drive the utensil opposite that motion. The Liftware spoon is very effective, but at $300 it is not a viable option for many people.

In MEAM 348 we were tasked with coming up with a passive alternative to the Liftware utensil. My team and I implemented a four-bar linkage with a diagonally mounted spring for gravity compensation. The initial prototype was successful at damping low amplitude vertical tremors, but it was very limited in its range of motion and had only one degree of freedom.

The goal of this research was to optimize the vibration damping of the four bar linkage and implement a second degree of freedom while keeping the device simple and low cost.

2 Four Bar Linkage Analysis

The initial proof of concept had shown success, but it was uncertain exactly why the linkage-spring system damped the hand tremor. With the apparent similarity to the four bar linkage system described in Nathan's "A Constant Force Generation Mechanism" (1985), it was determined that the mechanism (**Fig 1**) was functioning as a gravity compensation system altered to return to an equilibrium position. Using the proportions and spring constants for gravity compensation, the system was modeled to determine the ideal overall dimensions and deviation from gravity compensation to provide the most vibration isolation.

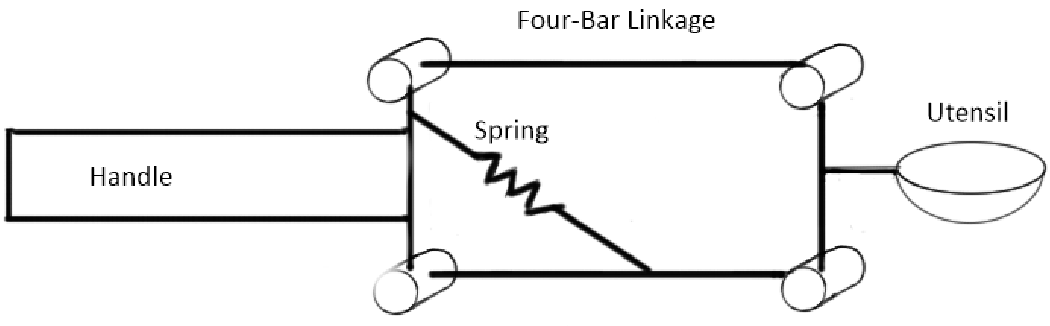

Figure 1*: A rough schematic of the gravity compensated four-bar linkage in the device*

After using Lagrange's method to solve the system as a complex two degree of freedom spring mass system, the mechanism was simulated in Matlab with applied harmonic forces from 4-12Hz, the range of frequencies for hand tremors. It became apparent that while this system could work in simulation, it was extremely sensitive to initial conditions. Because of this sensitivity it was impossible to determine the exact ideal mass, dimensions, and spring constants. The simulation did indicate that a heavier utensil, longer horizontal linkage, and spring attachment close to the utensil end provided the best conditions for vibration isolation.

3 Initial Designs

3.1 Design Constraints

The goal of this project was two-fold: optimize the vibration isolation mechanism as described above and design a viable consumer product implementing this mechanism. After the simulation did not give any strict values needed to give ideal isolation, the ergonomic design considerations became driving factors. Isolation is maximized by a heavier utensil and longer horizontal linkage, but a 1ft, 2lb spoon is not useable. It fell to prototyping to determine the right balance between vibration isolation and usability.

3.2 Rough Prototypes

The initial designs were single degree of freedom four bar linkages with adjustable tensioning of the diagonal spring. The arms were easily replaced to test how short the device could be before it was no longer useful. These prototypes suggested a minimum linkage length of about 3" and a utensil mass of 200 grams were as small and light as the device could be.

4 Second Degree of Freedom

4.1 Goal

The initial design and prototypes all had a single translational degree of freedom (DOF) implemented with a planar four bar linkage. This was the most important aspect of the project because the vibration isolation is more complicated with gravity compensation. However, a single degree of freedom device would be useful for only a small subset of ET patients while the majority have 2 or 3 DOF tremors. For this reason and to make the device comparable or greater in functionality than the Liftware utensil, a second translational degree of freedom was added along the horizontal axis perpendicular to the centerline of the utensil.

4.2 Initial Implementation

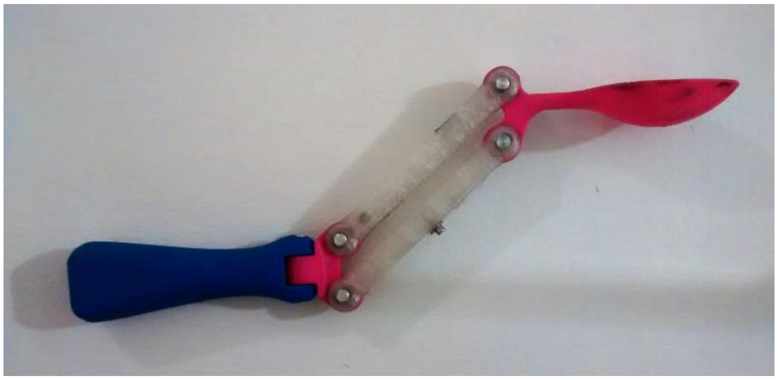

Figure 2

In addition to main four bar linkage, the first semi-functional 2 DOF prototype (**Fig 2**) included a single vertical axle between the handle and the linkage around which the linkage could rotate in an approximate 120 degree arc. A spring in the handle was connected to the rearmost point of the coupling with a nylon wire. Angular displacement of the linkage would tension the spring and return the linkage to the centerline. The pieces were printed on a MakerBot and assembled with machined axles and low-friction plastic bushings. The spring is contained in the upper arm and connected to the end closer to the spoon. A wire connected to the spring wraps around a pulley closer to the handle and then connects to the lower arm back at the spoon end.

4.3 First Full Prototype

The printed prototype was effective in the first degree of freedom, but the vertical axle and spring in the handle combination was ineffective. To increase to proportional return to equilibrium of the second axis, the axle was tilted forward fifteen degrees so that angular displacements created small vertical displacements. Theoretically this design would not need springs for the second degree of freedom since gravity would be doing the work of returning system to equilibrium. Also since the previous prototype did not have sufficient mass and weight distribution for proper functionality, the next prototype (**Fig 3**) was machined out of aluminum with a large steel utensil portion for the proper mass.

Figure 3: *The first usable prototype*

This iteration worked quite well, but was still ineffective at isolating non-trivial tremors in the horizontal axis. It was also far too long for comfortable use at 4.5" from the end of the handle to the beginning of the spoon.

4.4 Five Bar Linkage

The benefit of the four bar linkage over a single bar directly linked to the utensil is that the four bar linkage keeps the handle and end effector parallel for any translational displacements. The single axis implementation of a second degree of freedom does not do this. So a five bar linkage mechanism was designed (**Fig 4**) to maintain parallel in both directions. This system had two upper bars and one lower connecting the handle and utensil. The three bars are mounted equidistant around a circle at both ends. Since each of the arms needs to move in 2 DOF at a single point, small universal joints replaced axles. The u-joints are rigidly mounted to both the arms and ends so that the utensil cannot rotate relative to the handle. In each of the upper arms a wire runs from a spring, around a pulley at the handle end, and to a connection at the utensil end of the lower arm.

Figure 4: The Five-Bar Universal Joint Prototype

At first this design used the same springs that fit the previous iteration. Because of the added dimension, this device no longer operates the same as the initial linkage that was analyzed. Back of the envelope calculations suggested to double the spring constant while keeping the same unstretched length. Even with the new springs, this design was not quite as effective as previous iterations at isolating vertical tremors, but there was now equal functionality in both directions. Despite the increase in the number of parts, this design had only 3.5” from the handle to utensil and a much smoother motion than previous iterations. Also with more in depth analysis this design could be optimized to a point that in both DOF there is sufficient vibration isolation for patient use.

4.5 Universal Joint Four Bar

After the success of the five bar linkage, an attempt was made to make a version of the four bar linkage with the tilted second axis that was comparable in length and weight to the five bar version. In this prototype (**Fig 5**) two universal joints were used to combine the vertical and first two horizontal axles. The intention was such that when the linkage swings side to side the lower bar would slide along its axle within the utensil mount because of the tilted mount of the u-joints. The utensil mount was designed with springs that push the arm back to the center of the axle and return the whole linkage to the centerline. Once machined, however, the play in the universal joints and around the axle allowed the linkage to swing without moving the arm along its axle. So while this was the most successful version yet at vertical tremor isolation, the currently loose second degree of freedoms makes the device useless.

***Figure 5**: The universal joints at the left are mounted at a 15° downward angle. The slot on the right is wider at the base to allow the planned horizontal motion.*

5 Conclusion

This project was overall a success. The two final mechanisms both have vibration isolation comparable to the Liftware utensil and are a viable length and weight. In the furue, the prototypes need to be outfitted with food safe spoons and put in the hands of essential tremor patients. In addition to ensuring the viability of the device, testing with actual ET patients will inform which design should be further iterated. Once the mechanism is finalized, the product design considerations need to be implemented. The device needs a handle that be can held in numerous orientations so that the user can grip the device in a way that aligns the plane of their tremor with the working plane of the device. A mechanism for easily replacing a washable utensil needs to be added along with a rubber sleeve around the whole mechanism to protect the linkage joints from spills. With these additions, the device could be a viable product allowing people with hand tremors to eat comfortably and without spilling.

6 References

Nathan, R., 1985. “A constant force generation mechanism”. Journal of Mechanisms, Transmissions, and Automation in Design, 107(4), pp. 508–512.