Haptic Grip Interface for Virtual Tools

by

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ABSTRACT

Interaction with virtual environments can be enhanced through the use of haptic interfaces allowing for the grasping and reorienting of virtual objects. In my thesis, I designed, built, and tested several devices that would enable a user to manipulate virtual objects through a two finger gripping mechanism. By investigating the ergonomics of grip design, I built a flexible and effective grip interface with the goal of minimizing its size and inertia. The final design of the gripper utilized a passive spring system with one-degree of freedom for each of the two fingers with the center of the grip always in line with the center of the gripper's orientation. In order to determine the position of the fingers, I attached infrared emitter/sensor pairs that measure the distance between the finger pads and the center of the gripper. This ambidextrous gripper will be further developed to include force sensors. This device will eventually be used for the manipulation of virtual objects and possible control of a telerobotic system.

The development and use of additional attachments to a tool handler such as the gripper would necessitate a quick change interface with the tool handler to allow for quick and easy placement and removal of the attachments. I designed, built, and tested a quick change interface utilizing a steel leaf spring placed on each of the attachments allowing for easy locking and unlocking of the attachment to the tool handler. The new device requires no alteration of the existing tool handler.

Thesis Supervisor: J. Kenneth Salisbury, Jr.
Title: Principal Research Scientist

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1 INTRODUCTION

1.1 Background

The addition of haptics, or touch feedback, to the realm of virtual reality, previously limited to merely visual and auditory feedback, has added a whole new dimension of realism to a user's interaction with his virtual environment. Presently, point interaction through a user's fingertip with the virtual world is available in the PHANToM Haptic Interface[1]. This feedback is an actual point force, not merely vibration or other pseudo-force feedback.

1.2 Purpose

The need to increase a user's interaction from more than a single point has risen as more uses of haptics in virtual reality become known. The next obvious step from a single fingertip interaction is a grip or pinch manipulation where two or more fingers are used together. This allows for not only touching and pushing object surfaces in virtual reality, but also for pulling, lifting, and squeezing of objects. Several previous solutions were tried in which two independent Phantoms were used simultaneously. Also, a tweezer attachment to the Phantom has been tested.

In creating virtual reality tools, realism is the goal. In order for a user to become effectively immersed in the virtual environment, interaction with haptic devices should be made as close to what the user thinks he is touching. Therefore, in building this device, attention must be paid to how the user interacts physically with the actual haptic device. This would necessitate as little physical contact with the gripper as possible beyond what the user expects to feel in the virtual environment.

2 PROBLEM STATEMENT

2.1 Design Constraints

In designing this device, there were several design constraints with which I had to work.

- a gripping device that can be attached to the existing Phantom arm without any major modification to the Phantom
- should be ergonomically designed to be comfortably used with the thumb and the forefinger
- should be ambidextrous
- ensure center of grip aligns with the center of rotation of the three degrees of rotation freedom of the gripper
- have a minimum of mass (inertia)
- occupy a minimum of volume
- employ a quick change interface

2.2 Design Options

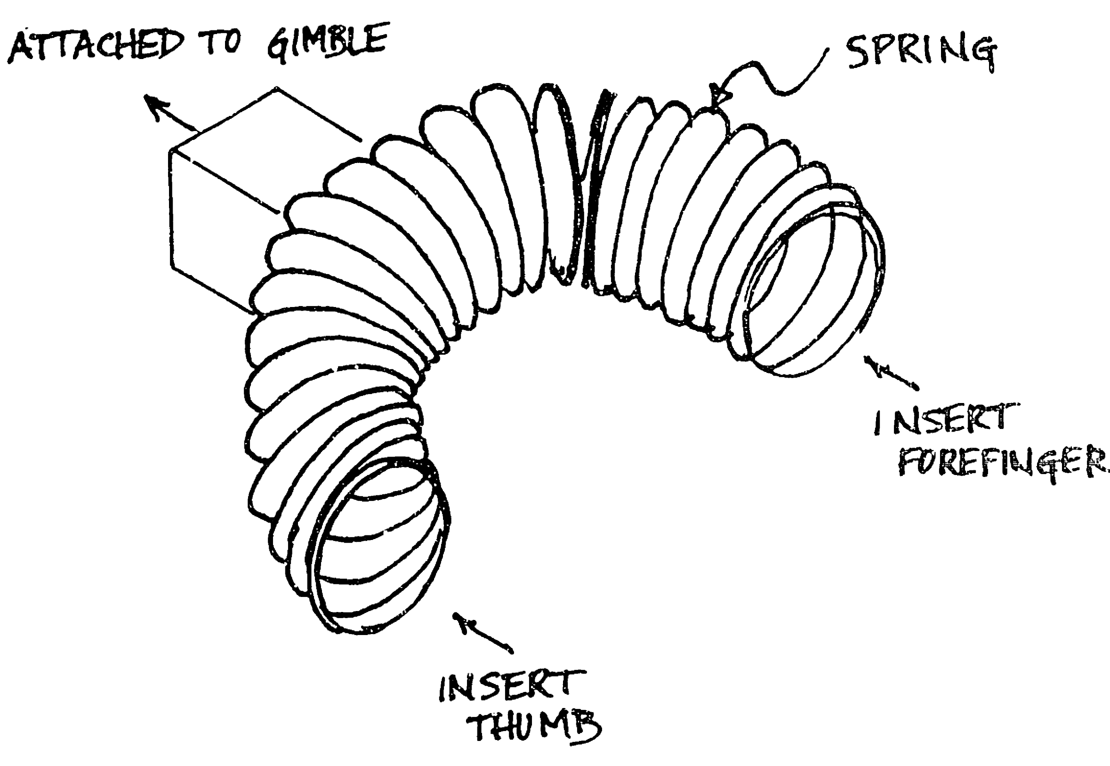
Several options and features that I had to consider on the gripper were

- actuated force feedback or passive feedback
- sensors to measure finger displacement
- coupled or decoupled motion of fingers

3 DESIGN CONCEPTS

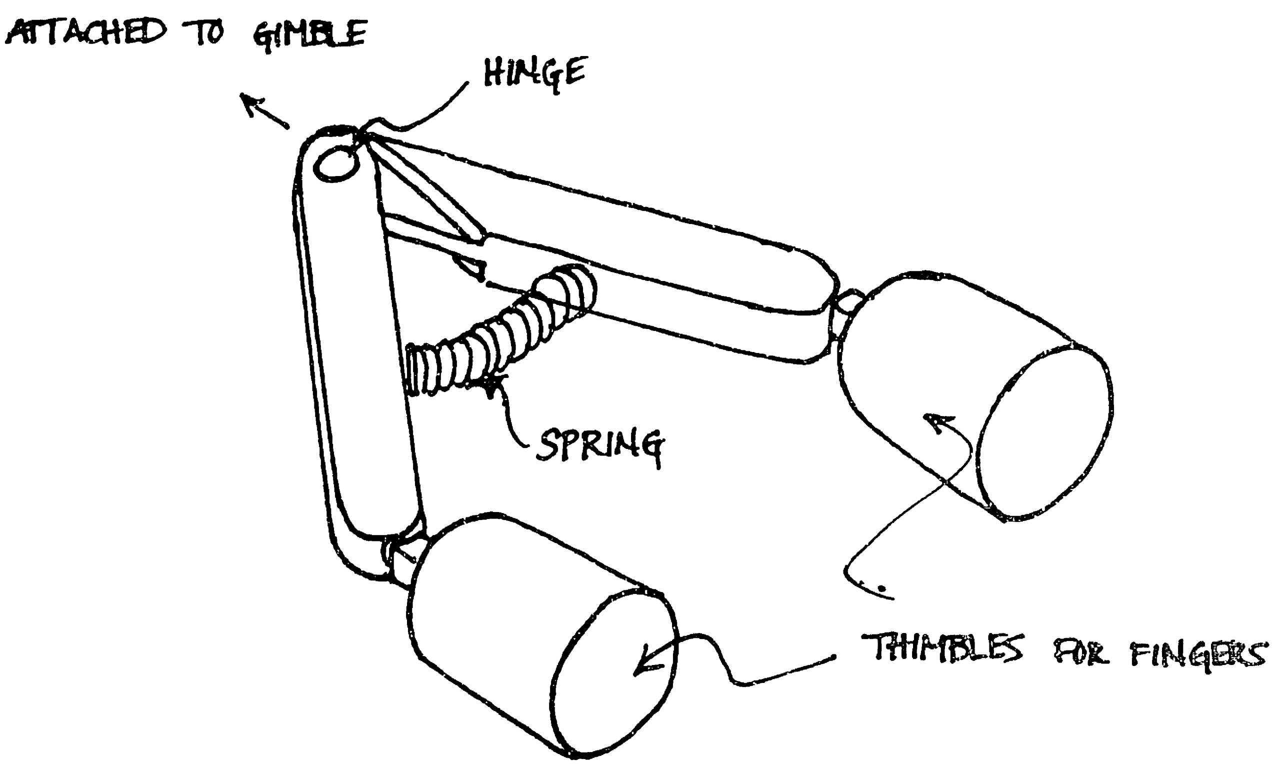
3.1 Bent Springs

The idea of using bent spring to provide resistance to the gripping motion employs a spring attached to a passive gimble that allows for three degree of orientation freedom. By inserting a thumb and forefinger into the two ends of the spring, gripping motion can be resisted. The simplicity of this design is an advantage, but because of the wide range of freedom of motion that can not be constrained, there ends up being too much undesired motion.



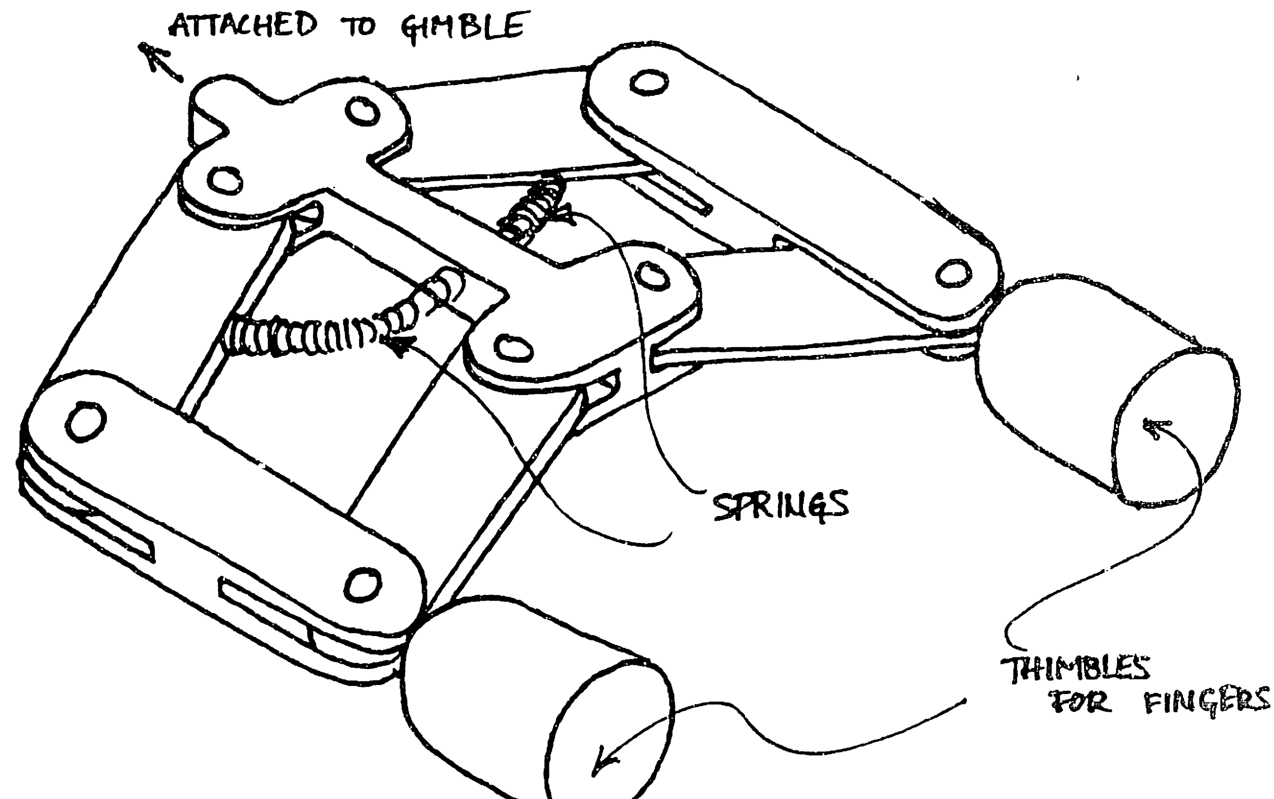
3.2 Tweezer

The tweezer design shown below limits motion to one degree of freedom from the hinge and employs a spring to provide resistance to motion. The motion of the fingers becomes an arc with radius equal to the length of the links. The mass of the gripper is not centered between the fingers which could cause some awkward torques on the user. Also, the fingers would probably have to be placed in thimbles because of the imbalanced weight of the gripper. These thimbles would add further restriction to movement, and they may feel unnatural.



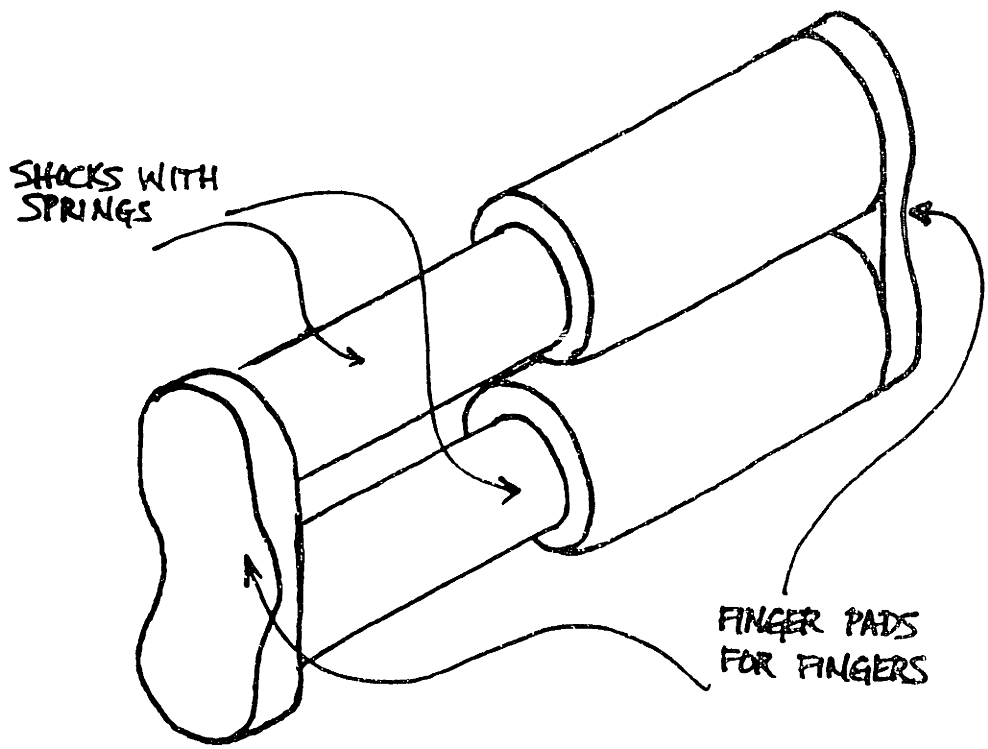
3.3 Four-Bar Linkage

The four-bar linkage design is similar to the tweezer design in that it limits motion to one degree of freedom. Many of the disadvantages listed for the tweezer follow also for the four-bar linkage.



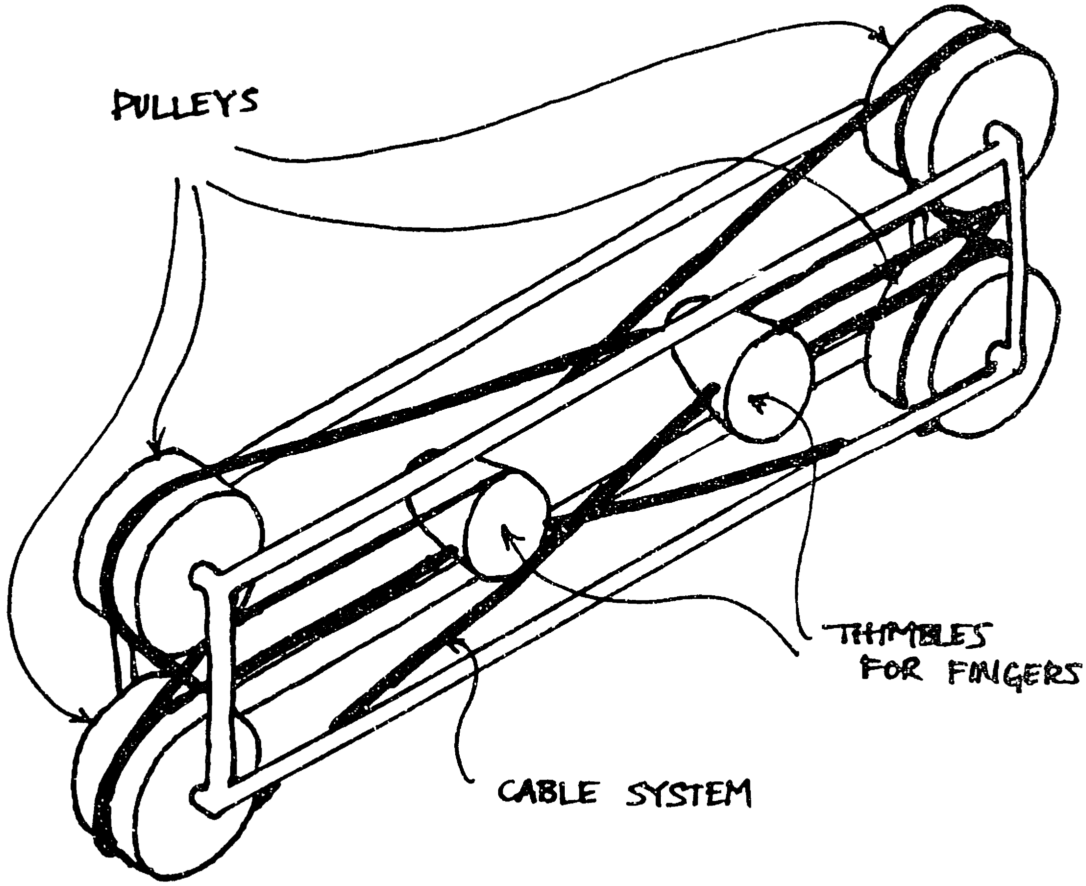
3.4 Shocks

The shocks concept employs a linear track as a guide for the fingers, and spring to provide resistance to motion. This linear track constrains motion to only one dimension thereby minimizing and compliance errors. Also, the shock gripper will be symmetric so that there would be no resultant torque on the fingers when the gripper is at rest. Because of this, there is no need to put the fingers in thimbles. Pads for the finger tips should be sufficient to keep the shock gripper stable. The pads allow the fingers much freedom in orientation because there is only a surface constraint on position. This allows for a more natural ergonomically comfortable feel of the shocks gripper.



3.5 Cables

The cable concept uses a system of keeping the center of the fingers' grip constant. The cable gripper couples the motion of the fingers so that when one finger moves, the other moves as a mirror image of the first, essentially, limiting the movement to one degree of freedom. While this motion limitation would have the most realistic feel to it because the exact motion of the fingers can be controlled completely by attaching motors to the pulleys, its size and mass become a problem.



4 DESIGN PROCESS

4.1 Gripper

In determining which design concept to use, I analyzed the different design constraints and made a Pugh chart to record the results (See appendix). Because this device is highly subjective in rating its performance because of human factors and ergonomics, I made several prototypes of the different concepts to test each device. From the tests, I was able to specify more exactly the design constraints that I originally made.

Because ergonomics and user comfort is essential in making virtual reality realistic, the gripper had to be made so that contact was limited to only the inside surfaces of the fingertips. Because of this, I decided to use finger pads rather than thimbles for user/gripper interaction to minimize unnecessary physical contact. Also, because the size of peoples fingers may vary, the use of finer pads ensure that any person could comfortable use the gripper without modification.

In order for the gripper to be as flexible and user friendly to any user, I decided that having an ambidextrous gripper would be essential in ensuring that the device could be used by right, left, or both hands. The finger pads also took care of this requirement by not having to make thimbles of different sizes for the thumb and forefinger.

Because the Phantom exerts a point force, it is necessary that the center of the user's grip align with this point source. There were several concepts that would ensure this either with a device that couples the motion of the two fingers or a symmetrical gripper that provides equal resistance to each finger.

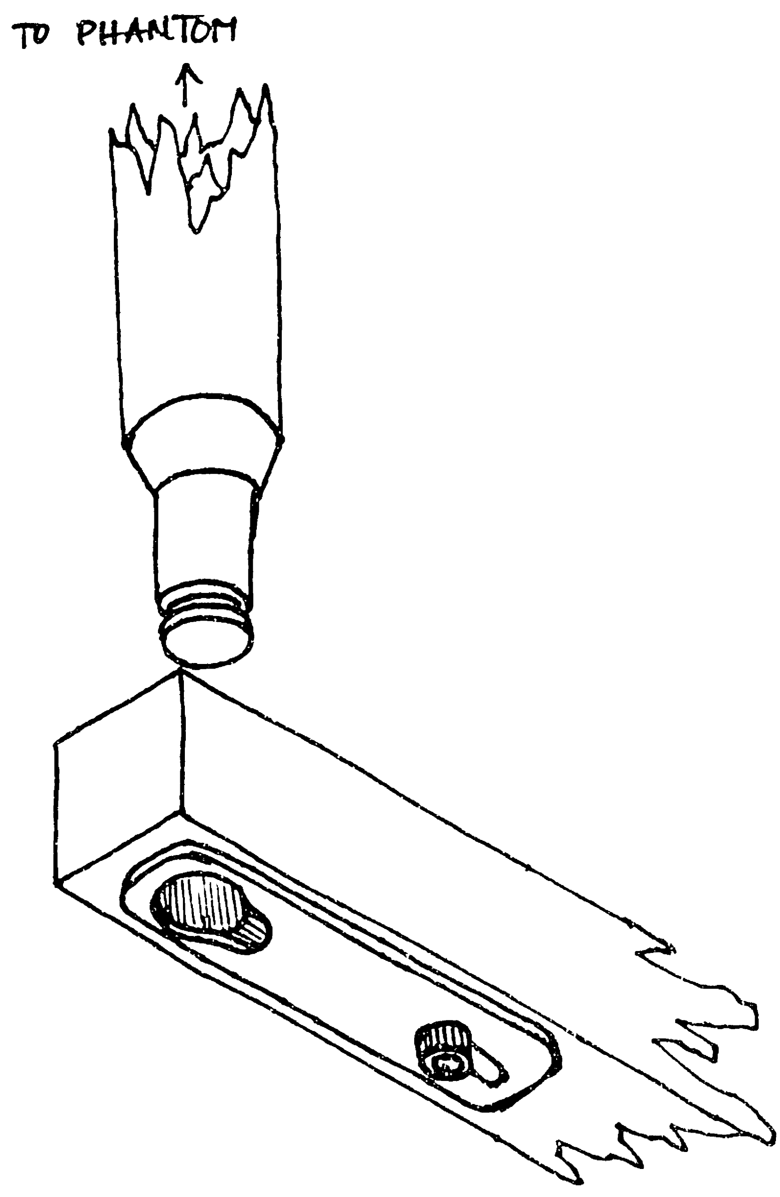
The requirement of a minimum of inertia and size of the gripper set a specification to make a gripper as close to the size of the user's grip with a minimum of materials. Also, by making the gripper's center of mass between the position of the user's fingers, there is no torque on the user's fingers and thereby makes the gripper less obtrusive.

4.2 Position Sensor

In order to determine the position of the fingers in the gripper, it was necessary to attach a sensor to the gripper. There were several options including linear potentiometers or infrared sensors. In order to minimize the size of the gripper, I decided not to use potentiometers but to use a reflecting infrared emitter/sensor pair. By attaching two of these sensors to the center support of the gripper and attaching a white reflective surface to the inside surface of the finger pads, I was able to determine the distance of each finger to the center of the gripper.

4.3 Quick Change

The gripper will be used on the Phantom and must be attached to it. Because there will probably future attachments to be used on the Phantom, I wanted to ensure a quick and easy way to lock and unlock the attachments to the Phantom without any permanent modification to the original arm. In order to satisfy this requirement, I built a quick change mechanism that would enable a user to detach and reattach an additional tool to the Phantom easily.



5 FINAL DESIGN

5.1 Design

In the final design of the gripper, I decided to used the shock concept to make a passive linear gripper using springs to provide resistance to motion. The reason for choosing this design is mostly from its simplicity. Some features of this gripper include an ambidextrous design that allow for quick and easy gripping and releasing. By decoupling the motion of the two fingers with a stop at the center of the grip, the center of the grip remained close to the center of the three rotational axes. The design was made with the intention of minimizing inertia (both translational and rotational) and volume of the gripper. This was accomplished by making the gripper only slightly larger than the actual distance between the fingers. Also, by making the gripper symmetric about the center of the rotation of the three axes, the rotational inertial was minimized given its specified geometry and mass. In order to measure the position of each finger in the gripper, an infrared emitter/sensor pair was attached to the central support. Then, by attaching a white reflective surface to the inside surface of the finger pads, the distance from each finger to the center of the grip was tracked. Because this gripper will be used on the Phantom, I designed a quick change interface that allows for fast and easy attaching and detaching of the gripper using a piece of leaf spring with a small slot cut in it to allow for locking of the gripper.

5.2 Parts List

4 - Springs (stiffness may vary to your specifications). Must have an inner diameter of at least 1/8"

1/8" ø Aluminum rod (about 12" in length)

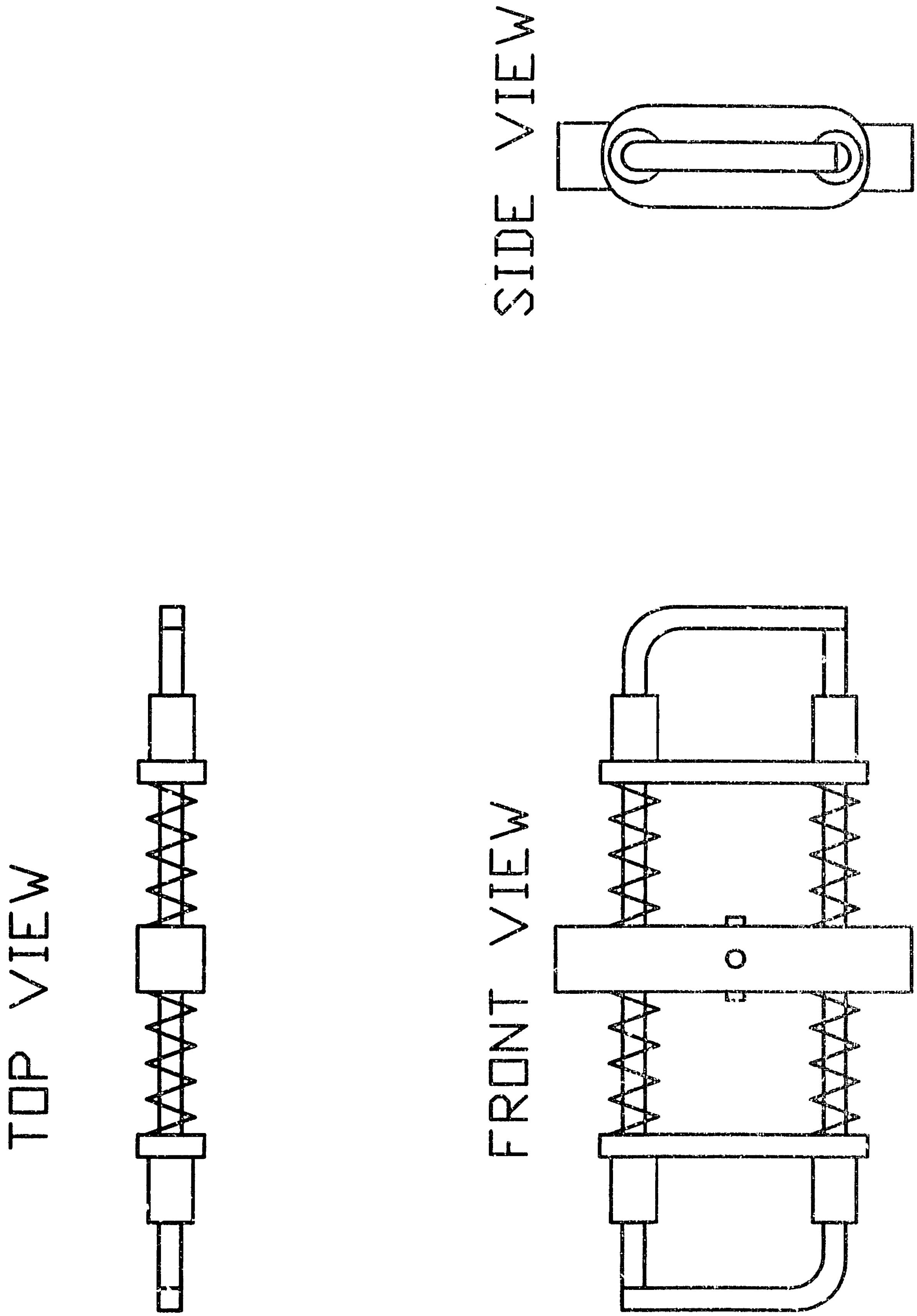
4 - Nylon sliders. Must have an inner diameter of at least 1/8"

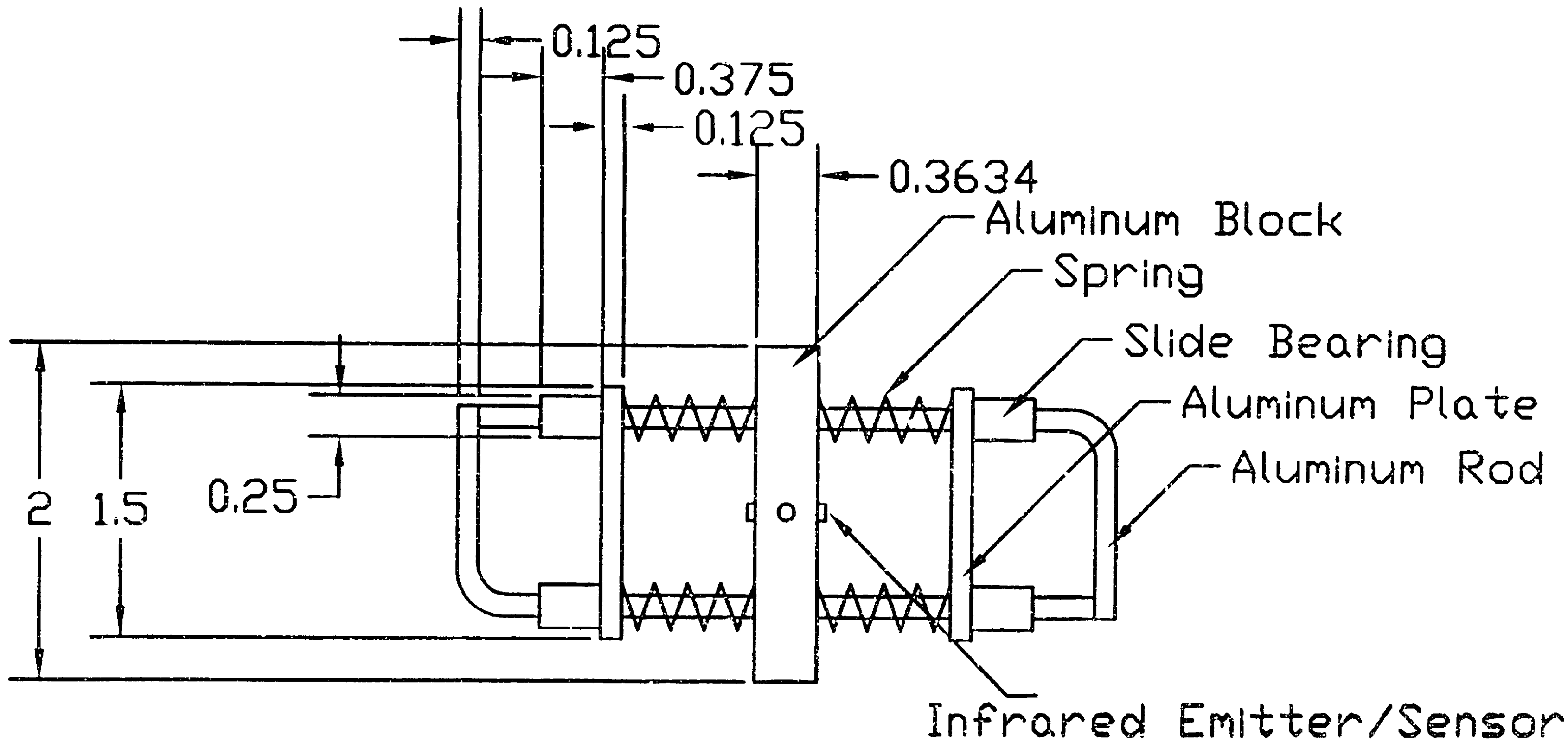
3/8"x3/8" Aluminum stock (about 2" in length)

2 - Miniature light reflection emitter/sensor. Siemens SFH900-2 series

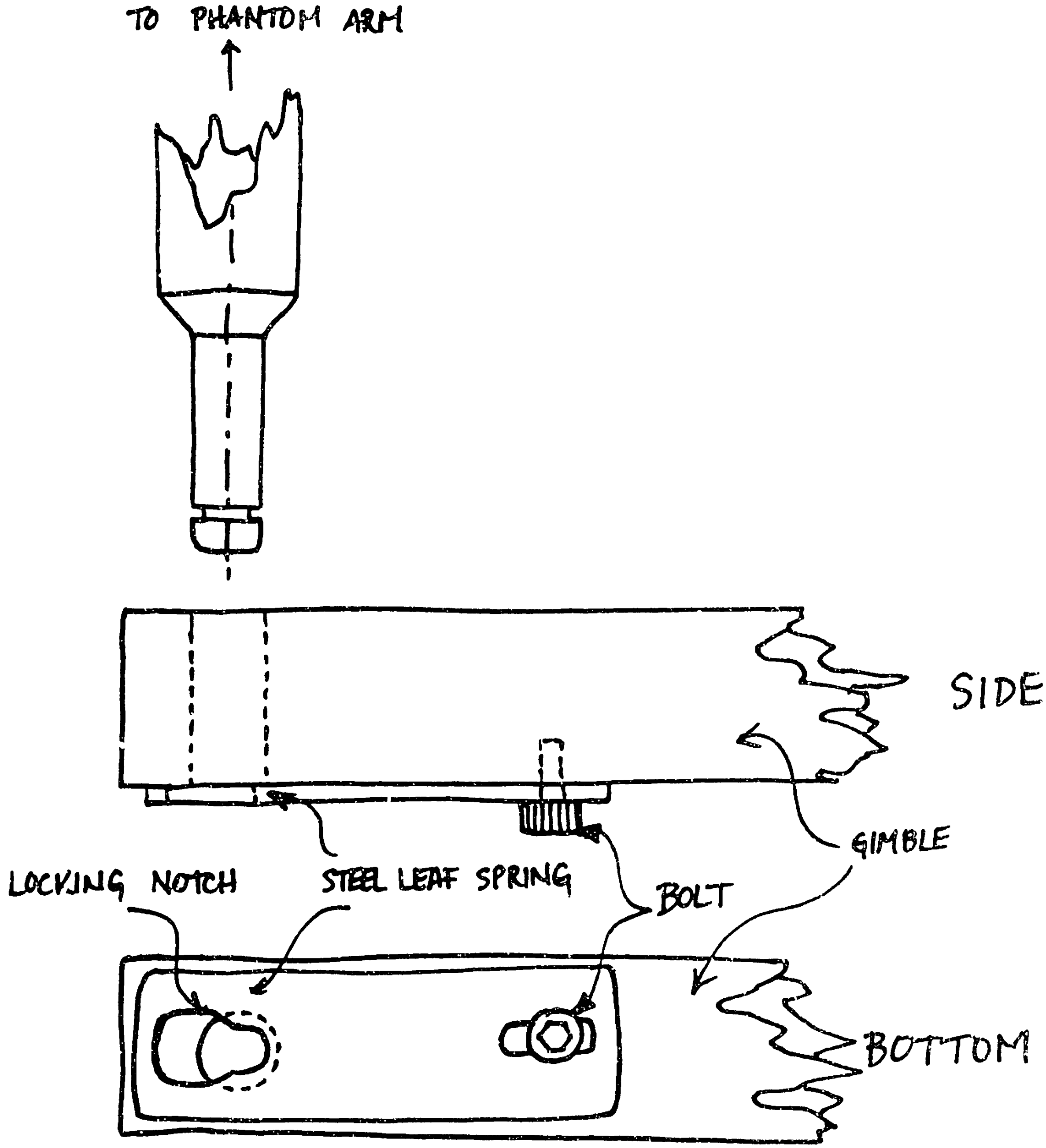
0.010" Steel leaf spring (about 3/8" wide and 1" long)

5.3 Drawings





All Dimensions in inches



TO PHANTOM ARM
SIDE
GIMBLE
LOCKING NOTCH
STEEL LEAF SPRING
BOLT
BOTTOM

6 CONCLUSIONS AND RECOMMENDATIONS

With the final design of the gripper attachment to the PHANToM Haptic Interface, all of the initial design constraints were met fairly well. By designing for simplicity and comfort, I made a passive gripper using springs for resistance and an infrared emitter/sensor for position tracking. The prototype of the device is fairly small and light, but with further development and design and the use of lighter materials, this could definitely be improved. The quick change interface is effective in allowing for easy attaching and detaching of any tools to be put on the Phantom.

For further development of a gripper to be used for virtual reality, I would recommend study in making an actuated force feedback gripper where the actual position of the fingers can be controlled. Also, by making the motion of the fingers truly coupled limiting the degrees of freedom of the gripper to one, the gripper's performance would be much more realistic to a user.

7 ACKNOWLEDGMENTS

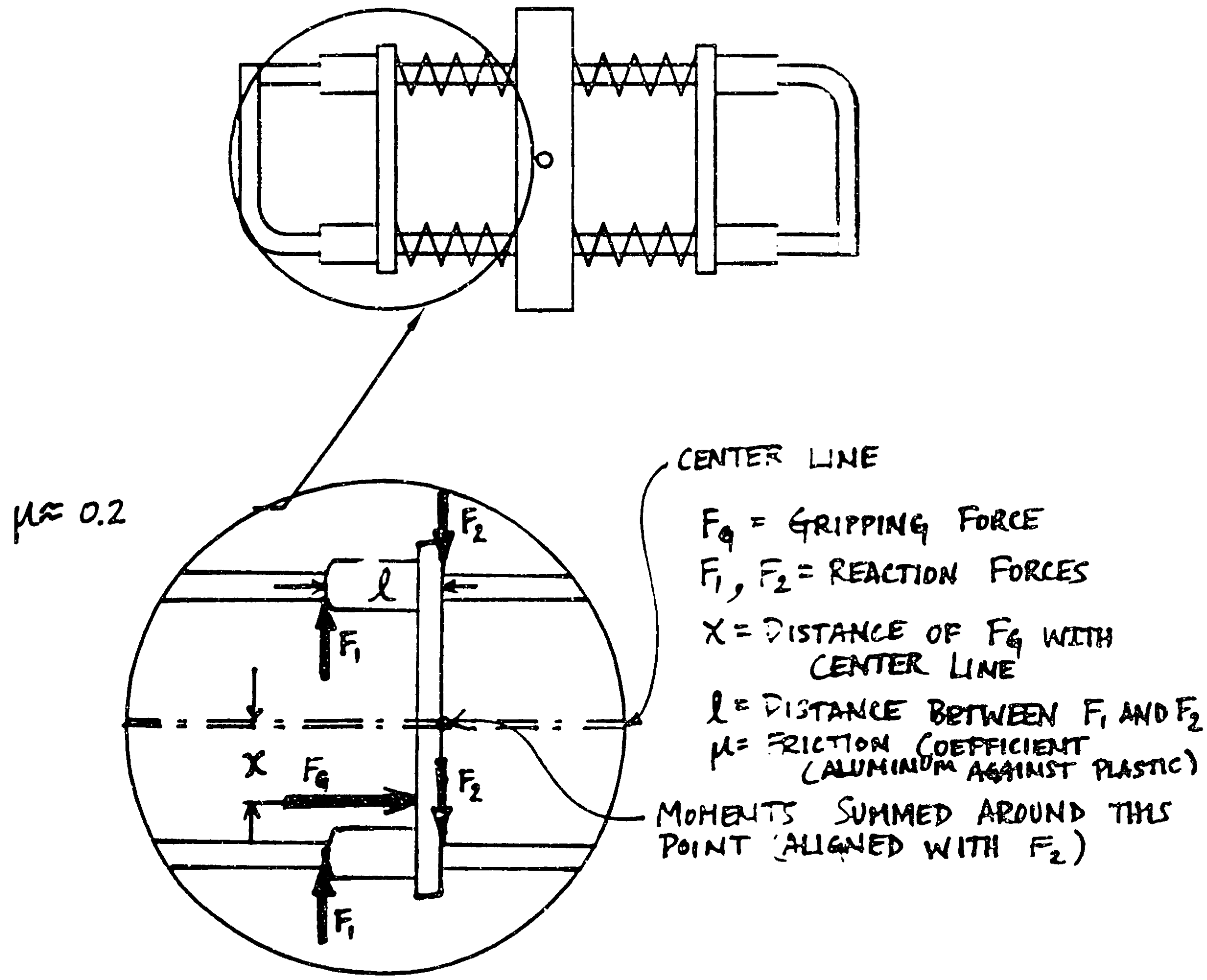
I would like to thank Ken Salisbury for helping me with the design of the gripper and the quick change interface, and for being such a cool advisor.

8 APPENDIX

8.1 Pugh Chart

	ORIGINAL TWEEZERS	BENT SPRINGS	TWEEZERS	FOUR-BAR LINKAGE	SHOCKS	CABLES
Grip Centered	0	0	0	+	+	+
Ambidextrous	0	0	0	0	0	0
Small Mass	0	0	0	–	–	–
Small Volume	0	0	–	–	–	–
Balanced Weight	0	0	0	0	+	+
One Degree of Motion	0	–	0	0	+	+
Complexity	0	+	0	0	0	–
Comfort	0	0	0	0	+	+

8.2 Engineering Design Calculations



$\circlearrowleft + \sum \tau = 0 : F_G X - 2F_1 l = 0$ $\qquad \sum F_Y = 0 : 2F_1 - 2F_2 = 0$

ASSUMPTIONS : $F_G \approx 0.2$ Kg
$X \approx .005$ m (IF FINGERS PLACED AS FAR FROM CENTER LINE AS POSSIBLE)

EQUATIONS : $F_1 = F_2$

PROBLEM : IF FRICTIONAL FORCES ARE $\approx \frac{1}{5} F_G$, HOW LONG MUST l BE

SOLVING : $(2F_1 + 2F_2)\mu = \frac{1}{5} F_G$

$(4F_1)(.2) = \frac{1}{5}(.2)$

$F_1 \leq 0.05$ Kg

$F_G x - 2F_1 l = 0$

$(.2)(.005) - (2)(.05)\,l = 0$

$l > 0.01$ m $\Rightarrow$ MY DESIGN EASILY SATISFIES THIS CRITERIA

$l_{ACTUAL} \approx 0.013$ m

9 REFERENCES

1. Massie, Thomas H., "Design of a Three Degree of Freedom Force-Reflecting Haptic Interface", SB Thesis, MIT EECS Department, May 1993.