Design and implement
a 2R Teleoperation haptic robot

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Abstract

Currently available haptic/teleoperation frameworks either are expensive, provide low-range haptic feedback, or lack sufficient rotational degrees of freedom. To tackle these drawbacks, this paper introduces an economical teleoperation setup, including two robots, serving as master and slave. The system is actuated by encoder-equipped DC motors, and the applied forces are measured by loadcells at the end effectors of the robots. ESP WROOM-32D boards are also used for time-delayed wireless communication. The manipulators are first designed in SolidWorks, and are then printed using a 3D printer. The stress and deformation analyses under a 5-kg load are also provided. The cost-effectiveness of the proposed system is highlighted by reporting the relatively low manufacturing costs. Furthermore, the technical specifications of our framework demonstrate its appeal as an alternative to current haptic devices, offering affordability and versatility.

In this project, Basic electrical and mechanical aspects (design, analysis, and manufacturing) are reviewed. However, if you are exploring additional information, you can refer to my paper titled “Cost-effective Haptic Teleoperation Framework: Design and Implementation”.

Key Skills: SolidWorks, Design, 3D printing, Robotics

Introduction

What is haptic teleoperation robot?

A haptic teleoperation robot combines teleoperation with haptic feedback, providing the operator with a sense of touch or force feedback during remote control operations. This means that in addition to controlling the robot's movements remotely, the operator can also feel the forces exerted by the robot on its environment or objects it interacts with.

Haptic teleoperation systems typically involve force sensors or other feedback mechanisms that transmit the forces experienced by the robot to the operator's control interface. This allows the operator to perceive and react to the physical properties of the remote environment, such as the texture of surfaces or the resistance encountered when manipulating objects.

These systems are valuable in various applications, including surgery, where surgeons can remotely perform delicate procedures with a sense of touch, or in tasks involving hazardous environments, where operators can manipulate objects safely from a distance while receiving tactile feedback about the environment.

Overall, haptic teleoperation robots enhance the operator's control and perception, enabling more intuitive and effective remote operation in a wide range of scenarios.

Why we are creating one?

The current availability of affordable haptic devices presents a challenge: they tend to be either too expensive or difficult to reproduce outside specialized laboratories. This lack of affordable options has drawn attention, prompting a call for solutions that offer accessibility without sacrificing quality.

Commercially available haptic devices, while valuable, often come with limitations. For instance, the Phantom Omni device has a restricted force range, making it less suitable for tasks requiring interaction with rigid external environments or providing extensive haptic feedback.

In response to these challenges, there's a growing need for a teleoperation setup that balances affordability with functionality. Many attempts have been made to adapt existing haptic devices like the Novint Falcon due to their cost-effectiveness. However, this approach presents its own hurdles.

The Novint Falcon, though budget-friendly, lacks rotational degrees of freedom crucial for implementing certain teleoperation theories, limiting its applicability. Furthermore, as it's no longer in production, scalability and further development of systems based on it are slowed down.

In light of these limitations, our objective is to develop a teleoperation system that meets the diverse needs of research while remaining cost-effective. Our contribution lies in creating a framework that not only addresses affordability but also offers wide-range haptic feedback, ample workspace, and intuitive operation for the user.

Figure 1: Falcon Haptic Device

Figure 2: Sensable Phantom

Design of the system

The main focus of this study is design and construction of two identical 2-DoF robotic arms, the combination of which will form an experimental setup for teleoperation. We started designing the links in SolidWorks considering making the setup as light as possible. The examination of the system's inertia is an outstanding concern, due to the significant disadvantages associated with excessive mass. To begin with, as the system becomes heavier, it requires more torque from the motors, which increases the overall setup cost. In addition, a heavier setup presents challenges in moving the master robot for the operator. To address this, we removed any surplus material in areas where it was considered unnecessary, ensuring the structural strength remains unquestioned. Furthermore, we determined the length of the links in a way to provide adequate workspace coverage without being overly large which results in mass increasing. The engineering drawings of the links for one robot are shown in Fig. 3. The 3D view of the assembled robot in SolidWorks is also shown in Fig. 4.

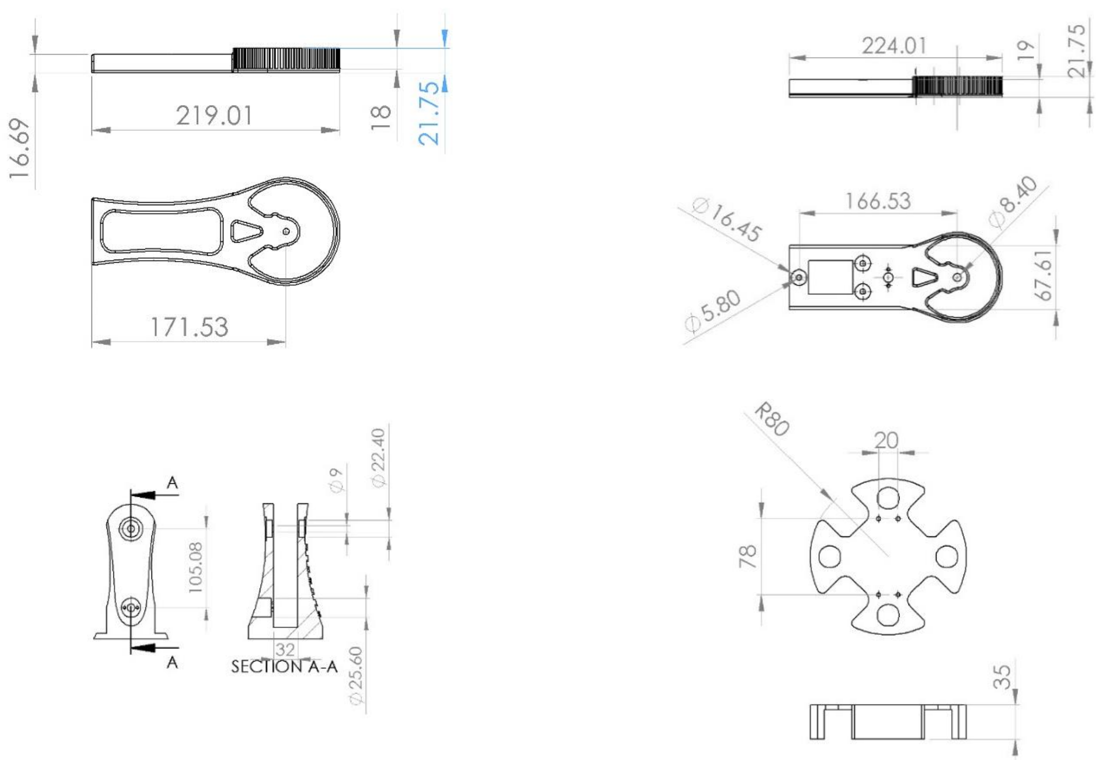

Figure 3: Drawings of the links of each robot (dimentions are in millimeters): a. Upper link b. Lower link c. Base link d. Base of the robot.

Due to the fact that all links will be produced using BACE lab's 3D printer, it is essential to acknowledge and account for any constraints and limitations inherent to the printer.

To accommodate the installation of 2 DC motors, two circular empty spaces are incorporated into the robot base and lower link, with essential supports embedded within.

Given the high speed of our motors, power transmission is achieved through a combination of belts and gears. The gear ratio of 1/5 ensures that for every 5 rotations of the pulleys and motors, there is 1 rotation in the subsequent link. This results in the conversion of undesired high speed into torque, enabling a wider range of haptic forces.

As belts are utilized, it is imperative to ensure proper tension. To achieve this, shafts and ball bearings are employed.

The load cell is a vital component of the setup. We have developed a new T-shaped 3D element, called the load cell holder, which securely fastens the 5kg load cell to the robot link. This allows for precise measurement of the force applied on the slave robot, with feedback relayed to the master to mitigate potentially damaging effects.

Links are interconnected using shafts and ball bearings, enabling convenient movement with minimal friction.

In addition to the base support and two links, a base is provided beneath all parts for three primary reasons. Firstly, it elevates the entire setup, facilitating a broader range of operations. However, this elevation also introduces additional safety considerations. Secondly, with the inclusion of electrical units, providing a designated space minimizes confusion associated with complex wiring. Lastly, this base also lays the groundwork for expanding Degrees of Freedom (DoFs) to 3R, enhancing the versatility of the system.

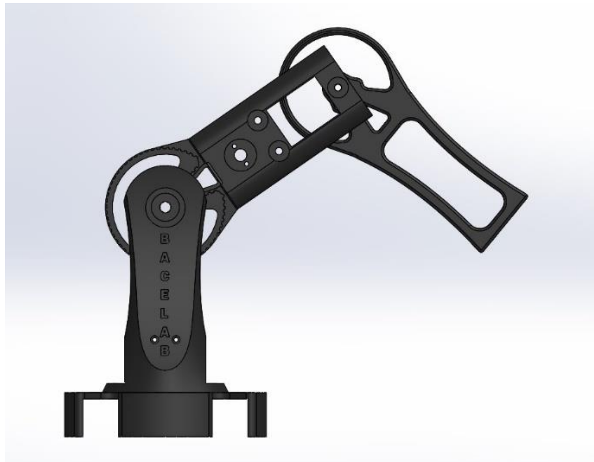

Figure 4 Side view of 2R robot

Analysis of the system

We carefully checked how strong the robot needed to be because we already knew how much force it would face. Through a process of trial and error, along with iterative redesigns, we optimized the robot to achieve the best possible outcome, culminating in the final design. Stress and deformation analyses were conducted for the 3 main links to ensure robustness and reliability.

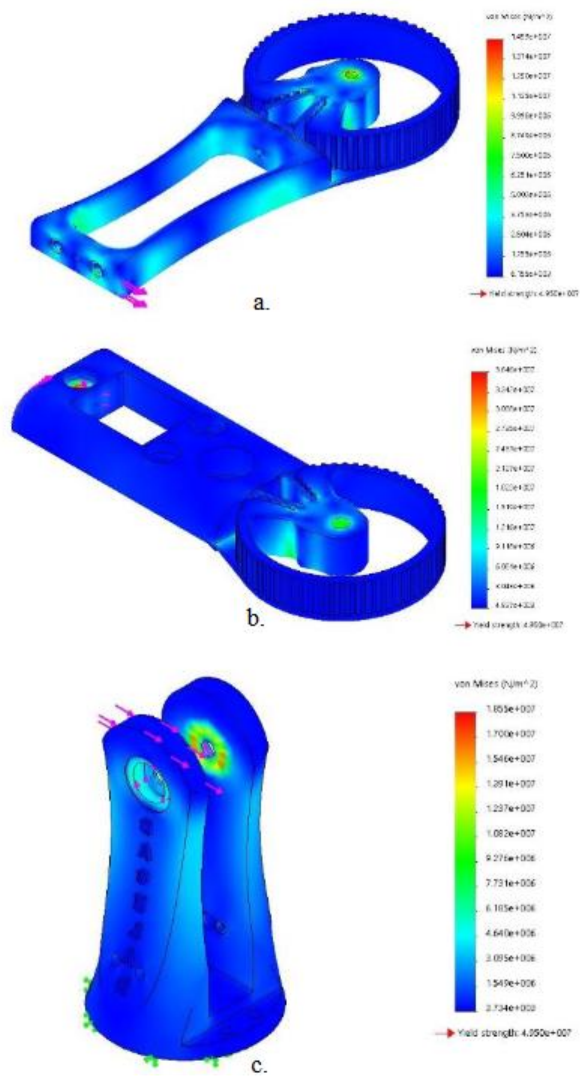

Figure 5: Stress analysis for: a. Upper link, b. Lowe link, c. Base link

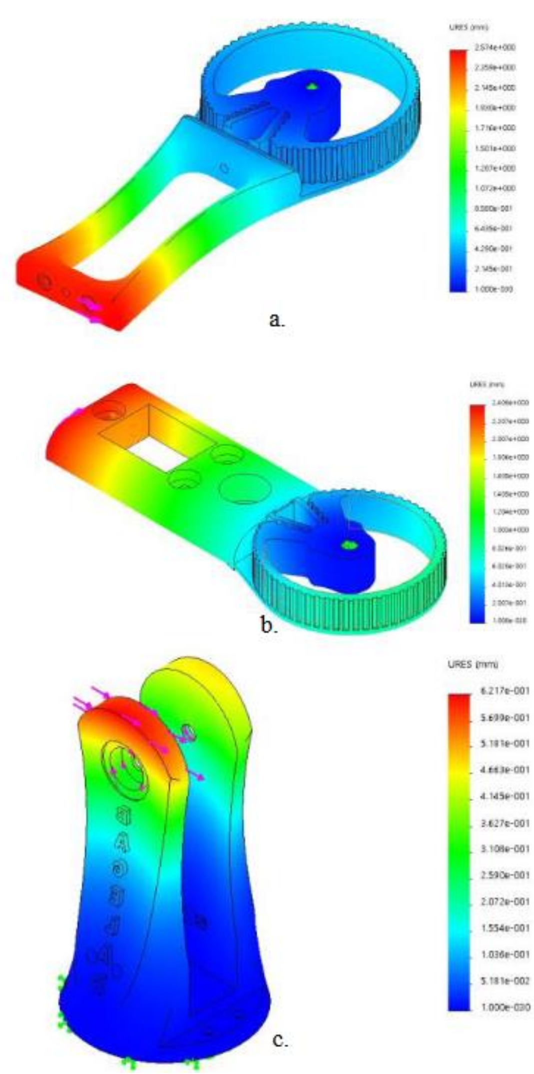

Figure 6: Deformation analysis for: a. Upper link, b. Lowe link, c. Base

Manufacturing of the system

Print Parts

In the beginning we start with printing components. We are using BACE lab 3D printer built by students and this printer use PLA(Polylactic Acid) as Material. To make G-code and also determine mechanical properties “UltiMaker Cura” Software is used.

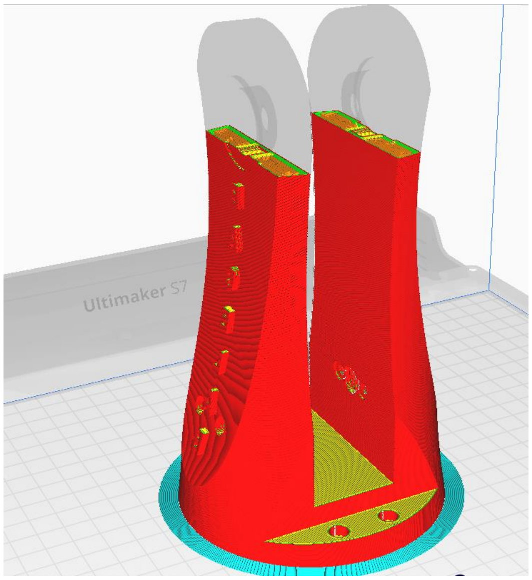

Figure 7: UltiMaker CURA Environment

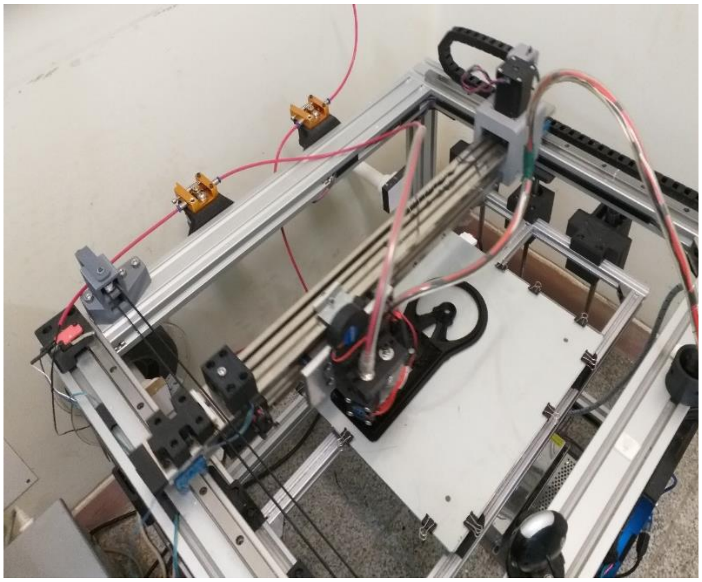

Figure 8: BACE Lab 3D printer

All Components Designed in Solidworks Must be exported as <.STL> files. Then, Cura will modify print setting and finally create a G-Code. In the end of this process printer will construct parts. Whole .STL files are placed in GitHub Repository .

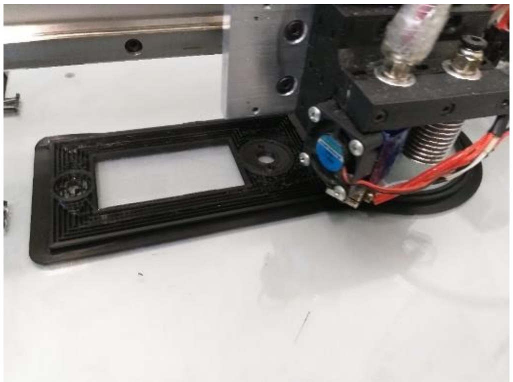

Figure 9: Printing Link 1

Mechanical properties and bill of material

Properties of designed teleoperation robot is given in following table

Joint parameters	*Number of joints*	*Joint type*	*Joints range of motion*
	2	Both Revolute	1st joint: [-55 °, 235 °]
			2nd joint: ±145 °

Mechanical properties	*Maximum speed*	*Maximum torque*	*Maximum voltage*	*Maximum current*	*Gear ratio*	*Maximum transmission torque*	*Link mass*
Joint 1	100rpm	1.5kgf.cm	12V	2.8A	3.6	5.4kgf.cm	152g
Joint 2	200rpm	1kgf.cm	12V	2.8A	3.6	3.6kgf.cm	103g

Load Cell	
Maximum allowable load	5kg
Sensing location	End effector

Controller and Feedback	
Encoder resolution	400 Pulse per revolution
Power supply voltage	12V

Max reach	35cm
Base weight	375g
End effector holder weight	5g
Total weight	635g

Other components:

DC Motor Driver	1
Pulley T5 16teeth	2
Belt T5	2
5mm shaft	3
8mm shaft	1
Ball bearing 8*22*7	2
Ball Bearing 5*16*5	6
Screw	10 (suitable size for bore)

Based on Estimation you can attempt to create this robot in USA 50$ and in Iran you can effort 30 million rial.

Setting up links

Base: We accommodated 2 hole for ball bearing and 8mm shaft. Also screw must be used to fix the Dc motor with robot. Pay a lot of attention to this affair. Then put pully on the Motor.

Link1: There are 3 bore in each side for 16mm diameter ball bearing. All 6 ball bearing are to support shafts. 1 shaft linking to next link and 2 utilizing as belt tighten. Put DC motor and then screw it to link. After that place pully on motor shaft.

Link2: 5mm hole to connect to Link1 and 2 holes to connect end effector

Put all together

First of all adjoin belt to links' gear. Second via 8mm and 5mm shaft make links and base coupled . Then put belt around the pullies and for link 2 and 1 set up belt tighten. Do not forget the end effector and screw it to the holes of link2. Then, locate load cell on it. You also can leverage wire cover and improve the wiring more efficient. Base support can be added to system too.

Figure 10: Exploded View

Extension To 3R

As mentioned in sections II and III, we have constructed two 2-DoF robotic arms. However, a third degree of freedom can be added to each manipulator so that the three-dimensional space within the workspace of the robots can be reached. Although we have not yet implemented the third DoF, we have conceptualized and designed it in SolidWorks. The scheme of the complete 3-DoF robot is depicted in Fig. 9

Figure 11 The 3D view of designed 3-DoF robot

Make it a Teleoperation Robot

To turn your described robot into a teleoperation robot, you can build two of them and establish a suitable communication protocol. Based on our experience, we recommend using ESP32, which can transmit data through various methods and is cost-effective. Additionally, you'll need a DC motor driver (ZK-BM1), a power supply, wires, and a PerfBoard. You can refer to our paper for detailed methods and results.

Acknowledge

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