MSc Robotics

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SenseGlove

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Internship report

Internship SenseGlove

Designing a haptic force feedback glove with active and passive force feedback elements.

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Chapter 1

Introduction

1.1 Introduction to force feedback haptic glove design for VR

Over the last few years, haptic devices in combination with virtual reality have become increasingly popular in both the research field and the business sector. SenseGlove is one such company that has taken over the market of haptic technology in VR. SenseGlove has made major advancements in force and vibrotactile feedback technology, modular and compact adaptable design, and approved quality and accessibility for haptic gloves [1]. These haptic gloves in combination with VR have been important in numerous applications to track the movements of the operator's fingers and form feedback tactile and force communication received from the control object to achieve a new level of accuracy in work with virtual and with real objects by converting virtual contact action into physical. Therefore these haptic gloves in VR are mainly used in applications such as: gaming, virtual simulators for learning or prototyping, marketing, medical rehabilitation and exoskeleton design, and telecontrol of robotic manipulators [2].

For designing a haptic glove two main functionalities need to be solved: measuring hand position and providing feedback for realistic interaction in VR. In my internship assignment I have been responsible for improving the feedback functionality of the glove, therefore the focus will lie on force feedback systems in haptic glove designs. For haptic force feedback designs in gloves we can consider sensing and transmission of force, and tactile, active, passive, or hybrid force feedback elements. The idea behind passive force feedback is that the operator's fingertips encounter resistance from the glove's structural components. A regulated damper, a brake, a latch or an electromagnetic clutch are mainly used in these designs. A spring controls the elements' return to their initial position. Such devices have the benefit of user safety and simplicity of design. The lack of active drivers makes it difficult to affect the operator's senses while they are at rest, which is a drawback from this simplicity of design. The idea behind active force feedback is the use of active drive which for example can be achieved by implementing electric, pneumatic, hydraulic motors and piezoelectric actuators. An advantage of an active system is its capacity to generate feedback on effort as well as motion and resistance. The active system can operate simultaneously with the operator's fingers at rest and without any movement from the operator [2]. Providing active force feedback in a haptic glove can be achieved through the use of simple actuators such as motors or solenoids, which can be controlled by a microcontroller. The microcontroller can receive input from the virtual environment, and use it to control the actuators and provide the appropriate force feedback to the user's hand. Thus, both passive and active actuation have their advantages for high fidelity and realistic experience in virtual reality applications. The development of new hybrid haptic gloves, which include active and passive actuation, has the potential to fully address actuation design requirements of handheld haptic devices such as a haptic glove. Due to the large passive torque capability, the stabilizing effects of passive actuators, the high bandwidth of conventional DC servomotors, and the synergy between actuators, hybrid actuation has the potential to increase the dynamic range of handheld haptic devices [3].

1.2 Motivation of topic

The objective in this internship assignment is making an active force feedback system from a passive force feedback system for the company. The development of new hybrid haptic gloves, which include active and passive actuation, has the potential to fully address actuation design requirements of handheld haptic devices such as a haptic glove [3].

1.3 Outline of plan and objectives

Therefore, to develop this glove's hybrid passive and active force feedback technology I analyzed, conceptualized and evaluated this topic. Firstly, I have analysed the state of the art by conducting a literature study and reading about the existing technology within the company. The outcome of the analysing stage is a program of requirements. Secondly, I developed and evaluated the concepts with the help of the requirements and built multiple prototype actuation designs. At last, I built a glove prototype with the hybrid actuation elements including hardware and programmed haptic responses, with relevant parts and resources from the company.

Chapter 2

Design concepts and prototyping

2.1 design approach

After the literature study, the program of requirements was reported and also visualized by making a morphological map as can be seen in **??**. After analyzing the advantages and disadvantages of each of these elements, combinations of these elements are made into models. 7 models were conceptualized:

1. **Series Elastic Actuator (SEA) module with DC motor**

   Already proven concept called SEA (series elastic actuator) which is a simple spring motor load system. The spring can handle conveying soft and hard surfaces while the DC motor can provide active force feedback. This module uses relatively cheap components and is modular since it consists of only a spring and a DC motor unit. In this module the cables are directly connected to the DC motor which is being damped by the spring inside the module on the basis of the output from the torque sensors. This design has as advantage that it can give very gradual force feedback with the right gear systems, however it can have moderate accuracy [4].

2. **Brakes with DC motor**

   This module makes use of an electromagnetic brake for the passive force feedback and a DC motor for active force feedback. As the brake is of the on/off variant the gradual force feedback needs to be implemented in the transmission system with for example a Bowden Cable transmission. This concept is a simple one and also modular as the string is only connected to a DC motor and a EM brake. This design has as advantage that it can lock in every position and that the torque can be directly measured, however a high gear ratio in the motor can result in a loss of transparency [5].

3. **Latches with Piezoelectric actuators**

   A module where a piezoelectric actuator handles soft surfaces and an electromagnetic latch the hard surfaces. The module would require a high supply voltage as both components are relatively voltage hungry. However, the amount of moving parts is lower compared to a DC motor resulting in a higher reliability. The module as a whole has low energy consumption but will require close cooperation between the actuator and the latch for hard surfaces due to the limited locking positions of the latch [6] [7].

4. **Twisted String Actuator (TSA) with controlled damper**

   An all in one module for sensing forces/actuating of the fingers. The twisted string actuators create tension on the cable by using the rotary motion produced by the motor to twist it. Translational transmission systems based on twisted strings coupled with electric motors (in this case a DC motor) can compose light-weight, compact, and mechanically simple actuators. The TSA module consists of a frame with a DC motor and an encoder, a force sensor to measure the load applied to the string, a pair of compliant beams or springs (as an extra damping system). This design has as advantage that it is compliant, energy efficient and has a high power density and large translational force. However this design is bulky and has a non-linear transmission ratio [8] [9].

5. **Electrostatic brakes with servo motors**

   The electrostatic brakes consist of 2 thin flexible steel strips separated by a dielectric. The metal strips slide freely when no control voltage is applied. Once a suitable voltage is applied the pair of strips form an effective electrically controlled brake by electrostatic attraction of the two plates. With the servo motor the length of the cables (which can be incorporated with the strip or exoskeleton) can be defined. The electrostatic brakes here lock the cables in their position. This design has as advantage that it is light, easy to implement with cables or linkages and has a large translational force. However it also has high voltage requirements and it has problems with counteracting the flexion of the thumb. [10] [11]

6. **Electromagnetic clutches with servo motors**

   In this module the electromagnetic clutch becomes a rigid body once activated making this module sufficient for conveying hard surfaces while the servo motor handles soft surfaces. The module has a simple design while still being fairly cheap, however a servo motor can not be repaired easily and needs to be replaced in case of a failure. The module will need a feed with a high amount of power due to the power hungry components. This module is also fast and accurate due to the use of a servo motor. [10] [7]

7. **Controlled damper with piezoelectric actuator**

   This module consists of a compliant spring acting as a damper next to a reliable piezoelectric actuator which is connected to the cables. A piezoelectric actuator has less moving elements than a DC or servo motor, however these actuators are quite expensive, especially when the design needs an actuator per finger. This design has as advantage that it has high reliability, low energy consumption and compliant. However it also has a high voltage draw and moderate accuracy. [7] [10]

2.2 Experimental setups

For the general test setup two systems based on the design models were tested:

1. SEA damping module for active force feedback with a compression spring.
2. compliant SEA control module with two linear springs.

We would like to test for each system how much load the system can handle and how the systems act with the use of different springs, and stiffness and damping terms using the general equations for mechanical impedance (to later extend on impedance control) [12].

$$F = K(x_r - x) + D(\dot{x_r} - \dot{x})$$

Figure 2.1 shows the designed damping module which was chosen for the prototyping design which represents the (1) SEA damping module for active force feedback with a compression spring. This module performed better than the compliant SEA control module with two linear springs because the setup was more rigid while still exerting proper force and damping. Therefore therefore this module is not included in the report.

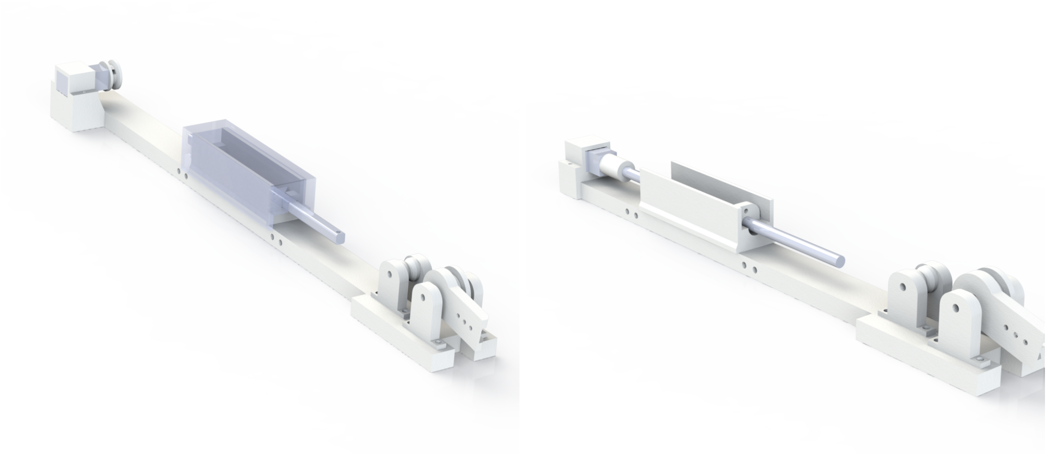

Figure 2.1: 3D representation of the final tested version of the SEA module in one finger. The render is made in Solidworks.

2.3 Prototyping

During the prototyping phase the tested SEA design was made designed more compactly and implemented in the hub of the glove. The SEA now consisted of a SEA box (which was based on a company design) with a spiral spring connected to a gear and pulley which pull back the cables passively. Then the SEA box is attached to a slider which slides along the worm gear of the small 5V DC motor. Figure 2.2 shows a 3D model of the glove prototype for one finger.

Figure 2.2: 3D representation of the hand SEA prototype consisting of the hub, slider module of one finger, SEA module, and motor holder. In this Figure the left shows the slided-in configuration, and the right shows the slided-out configuration. The render is made in Solidworks.

Chapter 3

Results

3.1 prototype design

The 3D model was replicated by 3D printing the parts and making the SEA module and the motor module. The resulting physical prototype is illustrated in Figure 3.1.

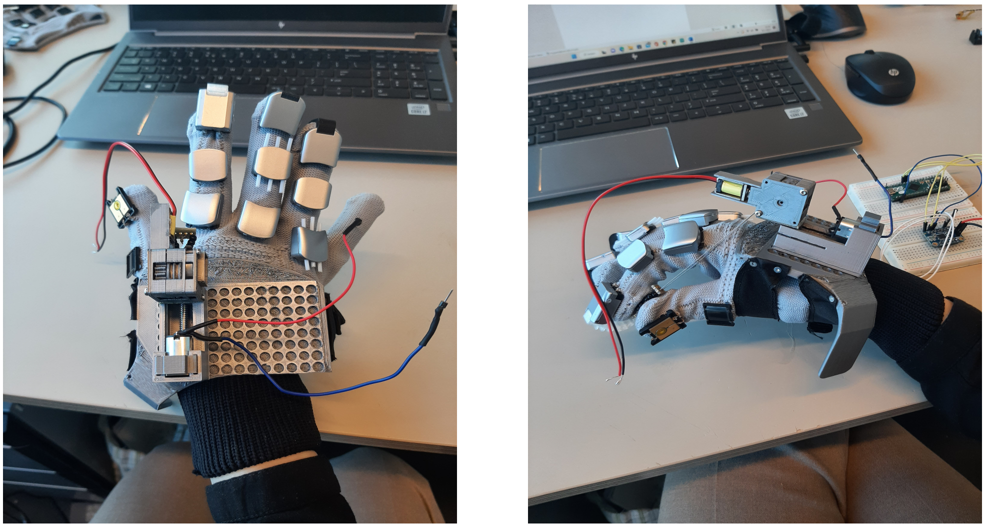

Figure 3.1: The final physical prototype design made from the 3D Solidworks model. The left shows the top view, and the right shows the side view of the prototype.

3.2 Testing

On the Arduino side, you can use the Serial.read() function to read the signal sent by the Python program and use it to control the motor and the solenoid latch. However due to time constraints software testing of the hardware devices were done in C++ in the arduino IDE.

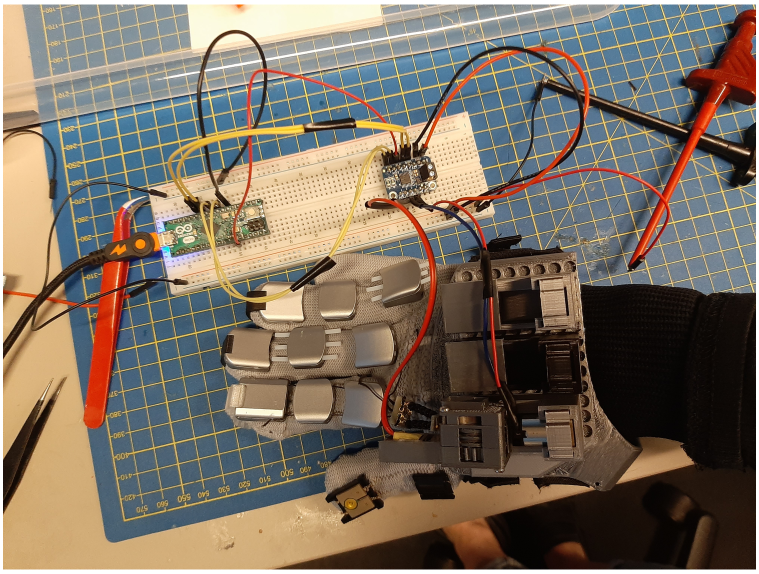

Figure 3.2: The final physical prototype design attached to the electronic circuit for testing individual parts.

3.3 Test setup

After prototyping and testing the hardware components a test setup was made for the next person to pick up the project. In this setup a user test will be performed where a virtual environment is created with a haptic environment in pygame. To connect the response of a DC motor and solenoid latch programmed in Arduino C++ to the virtual environment in Pygame, Serial Communication is used. Impedance control is then implemented in the prototype to reflect the forces of the virtual environment. Several force fields are then introduced in the virtual environment that produce a sensation (texture, bumps or holes) to test fidelity of the interaction with these force fields. To test braking with the prototype a toggle is added that introduces a virtual wall. Then the stability and passivity of the simulation with the prototype is tested with the wall stiffness. The following user test can be performed:

1. **Empirical studies on the sensation felt by the user**
   The user senses implemented forces (such as virtual spring, gradient or gradual braking) while colliding with their hand on the wall, feeling textures, interacting with virtual holes and bumps [13].

2. **Monitoring accuracy and time while the user performs a certain task with the prototype.**
   This task itself is modelled with the appropriate haptic feedback forces (such as performing a surgical task) to test out how well a user performs with the sensations felt with the prototype.

Chapter 4

Future Work

4.1 Hardware and software improvements

To extend on this project, it would be useful to add an encoder or a potentiometer to the SEA module of each finger. These additions are used used as a feedback device to help the module reach it's desired angle or state for more accurate force feedback in the SEA module. In order to extend on the simulation for testing, a virtual reality environment can be made in Unity for 3D visual object or obstacle representations.

4.2 impedance control

Sadly due to time constraints it was not possible to implement impedance control in python with a virtual environment with the prototype design. It would therefore be interesting to build upon that in the future by adding an impedance controller since it gives better transparency in free space, it's compliant, provides accurate force control and robustness.

4.3 Haptic Rendering

In future projects the prototypes can be further tested by simulating virtual textures. This is done by patterning the value of the rendered impedance as a function of the position of the user. Other tests to reach the goal of realistic force feedback in VR can be by adding virtual walls or shapes using pygame setups. In the results the initial setup has already been given for both impedance and haptic rendering, however due to time constraints these tasks have been handed over to the next person taking over my project.

Chapter 5

Reflection

5.1 Experiences

Looking back on my experience in SenseGlove I have noticed that I have not only put my engineering skills to practise but also experienced working on projects in a small company. Before I only had experience by acquiring knowledge in courses and experiencing research in my thesis. The new working experiences I have gained are mainly: actively participating in an ongoing project in the company, working together with colleagues, interns or thesis students in the department and taking initiative in my project by scheduling meetings, making a time-line and deliverables. Other experiences I have gained that more related in the robotics domain are: making iterative design/test setups for an active force feedback system, choosing and testing the required hardware for the designs, prototyping by using available hardware and 3D designing and printing parts, basic electronics skills, and setting up test software and connecting this to the prototype. Next to gaining these new experiences I have also learned that I really enjoy working in the field of haptic robotics in combination with Virtual Reality. During this internship I have focused on hardware design, prototyping and testing. However, in the future I would like to learn more about the software side in this field

5.2 Acknowledgements

I want to give my special thanks to my company supervisor Johannes van Luijten and my project partner in the first half Rogier Ketwaru for all the help and feedback.

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