Design and Test of a 1 DOF Haptic Device for Online Experimentation

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***Abstract*—This work describes the design and testing of a 1 degree of freedom (DOF) haptic device, for interaction with virtual reality (VR) applications. This device was designed so that it could to be easily assembled by anyone at a reduced price. Instructions for device assembly, as well as some VR applications are available online. The tests performed on the device proved that, despite its low cost, it is able to provide users with a good haptic experience and is adequate for not complex applications.**

***Index Terms*—1 DOF haptic device, haptic interaction, virtual reality.**

I. INTRODUCTION

One notable means of increasing immersion in virtual reality environments is by making use of sensorial devices such as haptic interfaces [1, 2].

In a broader sense, the term haptic relates to the study of touch and tactile sensations [3]. As such, a haptic interface can be defined as a system capable of providing tactile and/or force feedback. These interfaces typically consist of electromechanical devices and have applications in numerous fields, including medicine, research, training, education, industry and aeronautics, etc. [4]. There are currently several haptic devices on the market, mostly with three or six degrees of freedom (DOF). These are available at a cost that can prove prohibitive for institutions or individuals intending to perform not complex haptic simulations, which could be performed with simpler devices.

The Hapkit is one example of a low-cost 1 DOF haptic device. This device, developed by a team at Stanford University, was designed to be easily assembled [5]. It interacts with the user though a 1 DOF joystick-like handle, that performs rotational movement. This kind of movement, as well as the low output force it produces, limits the range of applications for the device. To the best of our knowledge, there are no commercially available haptic devices with one linear DOF, although some suppliers admit to build such systems on demand, at a higher price. Therefore, we identified the need to develop a 1 DOF haptic device capable of providing linear movement with high output force.

We designed this solution in order to be available as an inexpensive and easy to assemble do-it-yourself (DIY) kit, with the intention of spurring people to become more acquainted with haptic devices.

Furthermore, we tested the device to establish some of its characteristics, so that it could be compared with other haptic interfaces.

II. SYSTEM DESIGN

We propose a device that allows linear movement of a slider knob along one direction, capable of applying adjustable bi-directional force in any point of its working range [6]. It is operated by manually grasping and moving the knob, through which the force sensation is transmitted. This design was based on a previous project, in which a similar device was built from components of obsolete equipment [7].

The device was designed under the principle that it should be easy to reproduce at a low cost. Thus, the use of low-cost and off-the-shelf components, easily found on the internet, was another self-imposed guideline. Moreover, by resorting to a 3D printer, it is possible to design functional parts with complex shapes that can be produced at a low cost. The system should also be easy to disassemble, to allow replacement of worn out or malfunctioning parts.

A small DC motor drives the slider knob: a toothed pulley, connected to the motor shaft, engages a timing belt whose ends are joined to a carriage, on which the knob is attached. The carriage includes linear bearings and slides on two metal guiding shafts. This combination provides the device with great capacity to withstand disturbing forces, while minimizing friction and ensuring high durability. To keep the belt under tension we used an idler wheel, comprised of two flanged ball bearings, mounted on another metal shaft. Belt tension is adjusted through a screw mechanism on the carriage. The knob also contains two ball bearings, to allow its rotation without increasing friction on the guides. An encoder mounted on the motor shaft allows indirect measuring of the carriage position. A depiction of the transmission mechanism is presented in Fig. **Error! Reference source not found.**.

The motor and pulley were chosen to provide the device with a force range of 20 N. The linear working range was fixed as 100 mm for knob movement. The overall dimensions for the device were set to be around 200×100×50 mm.

The electronics for the control circuit in the device have also been further optimized, in order to lower their total

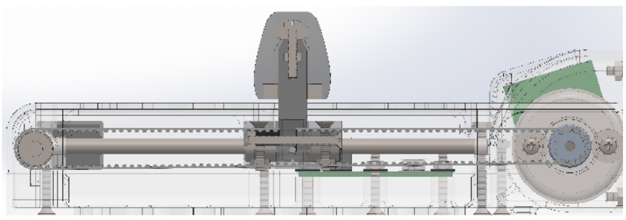


Figure 1. Side cross-section of the device, modeled in CAD software

cost, and achieve greater performance and efficiency in a smaller footprint.

A computer, that interfaces through a USB connection reads the knob position and sends the matching force value to the device, depending on the running software.

Finally, we estimate that the total cost of materials for the device is under 80€.

III. ONLINE SERVICES

Some software applications that can be used with the haptic device are available at [8], where they are referred to as “VR applications with haptic interaction”. On the same webpage all the files and information necessary for replicating the device are available, under “do it yourself 1 DOF haptic” (Fig. **Error! Reference source not found.**). These include:

- Every file for 3D printing the device (in STL format);
- A complete part list, detailing the required information for procuring the remaining parts;
- An assembly manual, instructing how to assemble the device;
- An assembly video, generated resorting to CAD software;
- A full schematic and component list for the electronics;
- A video, displaying how the haptic device interacts with one of the available applications.

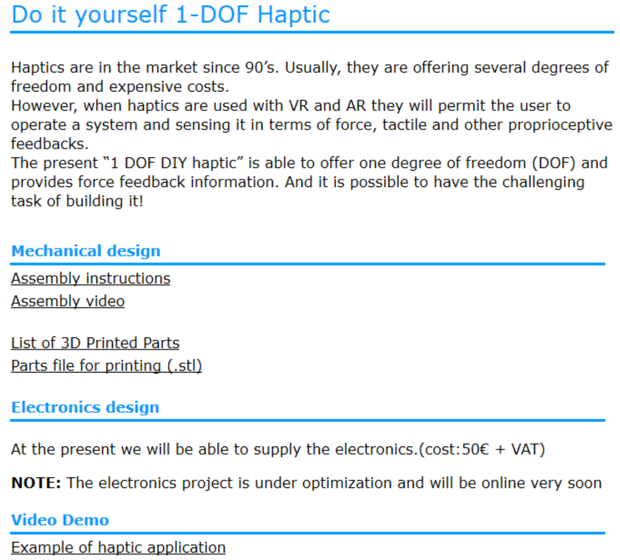
The electronic control circuit can also be assembled by anyone; however, we must supply them with the preprogrammed microcontrollers.

IV. TESTING AND RESULTS

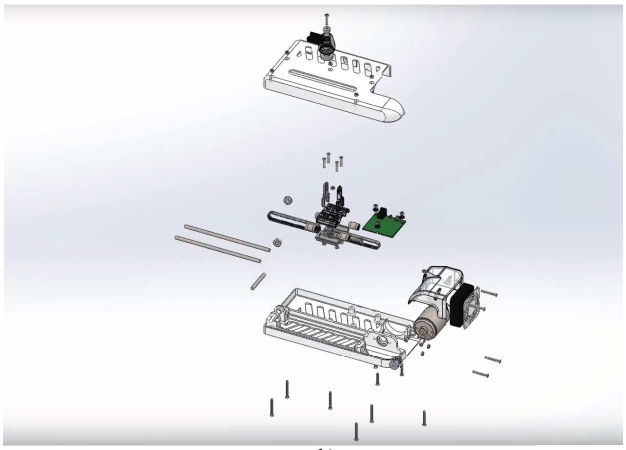
From a functional standpoint, the main guideline followed when designing the new version of the 1 DOF haptic device, was that it should perform as well or better than the previous prototype. Throughout development, this parameter was regularly assessed by testing each iteration of the device with the applications it was supposed to interface with. Upon reaching the final prototype (Fig. 3 and realizing we were satisfied with the interactions it allowed, we decided to further characterize the device, in order to fully understand where its capabilities and limitations lie.

In spite of the increasing popularity of haptic device development [4], there are still no established metrics for universal performance comparison across haptic devices [9-11]. As such, parameters for testing were chosen from [9] and [11], based on their effect on actual usage of the device and ease of implementation. The tested parameters were:

- Static friction force;
- Peak force:
  - Short transient peak force;
  - Long term peak force;
- Peak acceleration;
- Total inertia;
- Peak velocity.



a)



b)

Figure 2. Example of the information provided on the website: (a) available files and (b) the assembly video

Figure 3. Picture of the final device prototype

A. *Testing methodologies*

Static friction was measured with a load cell that was placed between the hand and the handle of the device. With the motor unpowered, the load cell was progressively pushed until the encoder registered movement, keeping record of the maximum exerted force.

For peak force measurement, the device was placed on its side, so that the knob moved vertically. The motor was set to maximum voltage (in order to exert maximum force) and the knob was loaded with different known masses. For each mass value we checked if handle movement occurred. In the case of short transient peak force, the motor was allowed to cool down to room temperature between each trial, while for long term peak force the device was tested continuously.

We measured peak acceleration with a MEMS accelerometer (MPU-6050) attached to the handle of the device, which was set to run at maximum voltage. A microcontroller acquired the acceleration data and transmitted it to a computer through a USB connection, where it was displayed using custom software.

Total inertia or apparent mass at tip (knob) was calculated from the peak force and peak acceleration values, through (1).

$$Inertia = \frac{Peak\ Force}{Peak\ Acceleration} \quad (1)$$

Lastly, we measured peak velocity using the encoder available on the device. The microcontrollers were programmed so that the encoder pulses were counted every 0.002 seconds and the maximum value was sent to a computer via USB, where it was displayed using custom software.

B. *Test Results and Discussion*

A summary of the results obtained from the performed tests is displayed on Table 1.

The obtained results are within the expected range and confirm the quality of the designed haptic device.

The device exhibits good backdriveability, with low inertia and static friction comparable to other high performance devices [11, 12]. The low static friction to peak force ratio is also extremely positive, since it assures the device has a good dynamic range. The remaining results are also within range of what is expected from a haptic interface [11, 13, 14] and reassure us that the device should provide good fidelity for haptic interactions.

V. CONCLUSIONS

In this paper, a 1 DOF haptic device that can be assembled by anyone at a low cost was proposed. This device was also tested, using a set of defined parameters. The tests revealed the device is capable of providing good haptic interactions, which is remarkable, especially considering its low cost and ease of assembly.

This device has been tested with children at the K-12 level, with promising results.

Instructions and other materials for replicating the device are available on-line, which we hope might encourage people to replicate it and further promote the use of haptic interfaces.

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