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# Marionette: a Multi-Finger Tilt Feedback Device for Curvatures and Haptic Images Perception

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## Abstract

Marionette is a haptic device designed to explore touch perception limits between real and device induced shapes. Its novelty resides in the support for 2D exploration over a flat surface and multi-finger capabilities. Marionette is able to apply inclination to four fingers with two degrees of freedom while the user moves the device as if it were a mouse. The device is aimed at enabling a new set of haptic user studies. Preliminary results suggest that the limit of curvature perception in 2D curves is mainly determined by the inclination information while touching with both one and four fingers. Additionally, Marionette supports haptic images such as maps, time changing functions and haptically enhanced telepresence.

## Author Keywords

Haptic perception; touch; curvature discrimination; multi-finger

## ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## Introduction

Haptic feedback is another way of exploring and sensing the world around us. The touch sense can be utilized to determine the shape of objects even if they are hidden or out of sight. It is even more important for visually-impaired people. Consequently, devices that can convey haptic information effectively are coveted.

The haptic information can be classified into kinesthetic and tactile. In the first one, the position of muscles and tendons are felt through the sense of proprioception. On the other hand, tactile pressure information is captured by mechanoreceptors that populate our skin tissue. Another categorization can be made attending to the mathematical point of view of the object that we are palming. Zeroth order information represents the direct position of the surface being touched whereas first order information is the derivate of the position; namely, the slope or inclination of the surface.

Haptic perception can be achieved in a passive or active way. In the former, the stimulus is applied into the user and it is moved while the user stays static. In the latter, the users control the exploration of the object by moving their hands. Generally, active touch exploration yields a more performant discrimination of shapes [1].

Curvature discrimination is a standard test in psychophysical studies [6]. In it, the users touch different shapes with a uniform curvature. More specifically, the user has to explore two different samples and decide which one was more convex. The curvature is the inverse of the radius of a sphere capped to the sample size.

During curvature discrimination of real objects, the main source of information is the slope [3]. Similarly, it was proven that removing the zeroth order information for curvature discrimination using a virtual device yielded similar performance as using all the orders of information or the real curvature [2][6]. These studies employed active touch, kinestheic information and tactile information without the friction cue. They have implications for psychophysical knowledge and for haptic interface design. However, they were limited to exploration in one dimension and with one finger. This is not particularly useful as most of our haptic explorations happen in two dimensions and with four fingers; for instance, feeling a relief map.

Some devices have been designed to study the curvature perception limit with one finger in 1D curves [2][6]. There are portable devices to explore 3D spaces but they only provide tactile feedback when encountering virtual objects [5]. Similarly, a wearable device was capable of providing encountered 3 degrees of freedom (DOF) to three fingers [4]. However, no device has been designed to study curvature perception limits with multiple fingers resting over a flat surface. Operating in a flat surface is a comfortable position in which the users can interact for a long time and leverage their previous skills with the mouse.

To study 2D tactile exploration of surfaces, we have designed Marionette, a haptic interface that delivers 2DOF tilt to four fingers. We present the preliminary user studies and some initial results on curvature perception limits. Additionally, we define future user studies involving haptic images and dynamic representations. Finally, we describe the Ghost Touch system, designed to haptically enhance telepresence.

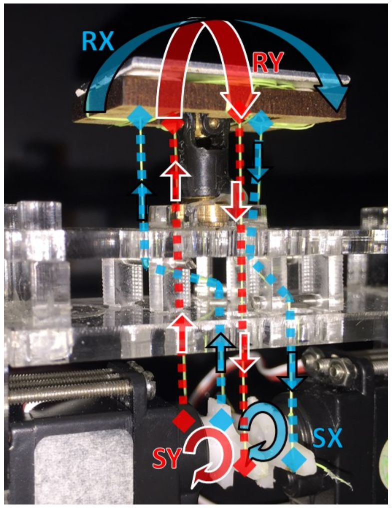


**Figure 1.** Threads connecting the servos with the plate.

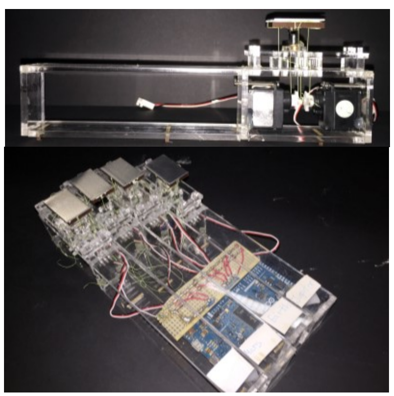

**Figure 2.** Top) one module. Bottom) Marionette with four modules.

## System Description

During normal operation, the user has one hand on top of Marionette, with each finger resting on a metal plate. To explore a virtual surface, the user moves the device over a horizontal flat surface in a manner similar to moving a mouse. During this process, the plates rotate to match the orientation of the patch that is beneath each finger in the virtual surface (Figure 3). Each plate can rotate with 2DOF. The size of the metal plates is 3x2cm and their operation angles are ±18 degrees for both rotations; this range is adequate for the planned user studies. The device is capable of applying a torque of 1 kg-cm with a speed of 500 degrees/s. The average accuracy obtained in the plates is 0.1 degrees.

Marionette is composed of four modules that can be socketed in a base with different slots to support different hand sizes (Figure 2). Each of the module is made of a rectangular structure in which two servos and a plate are held. The plate is fixed to the module with a universal joint permitting 2DOF rotations. The torque is transferred from the servos to the plates by means of two threads channelled with metal rods (Figure 1). An OptiTrack Duo captures the position and orientation of Marionette and sends them to a PC. Then, the PC calculates and sends the desired servo positions to an Arduino Duo board through the serial port. Finally, the Arduino board applies the corresponding PWM signal to the servos (Figure 4).

Marionette has an infrared marker attached to it. Thereby, the OptiTrack device placed above Marionette can estimate its position and orientation to send them to the PC. Then, using the dimensions of the user's hand the position and orientation of each finger can be obtained since they are fixed relatively to the marker.

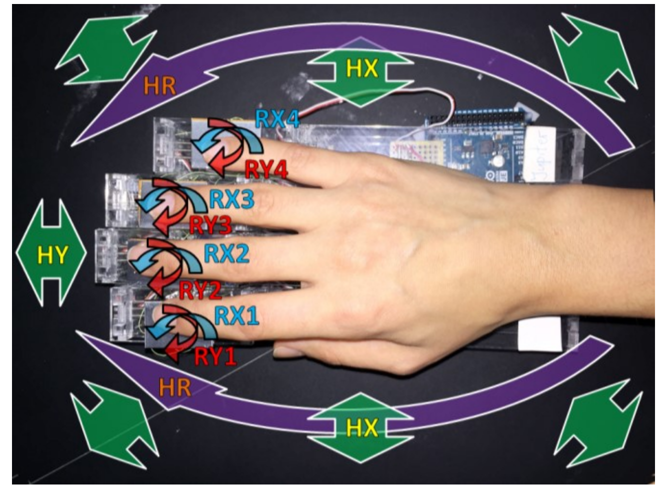


**Figure 3.** Marionette applies 2DOF tilt to four fingers while the users moves or rotates it over a flat surface.

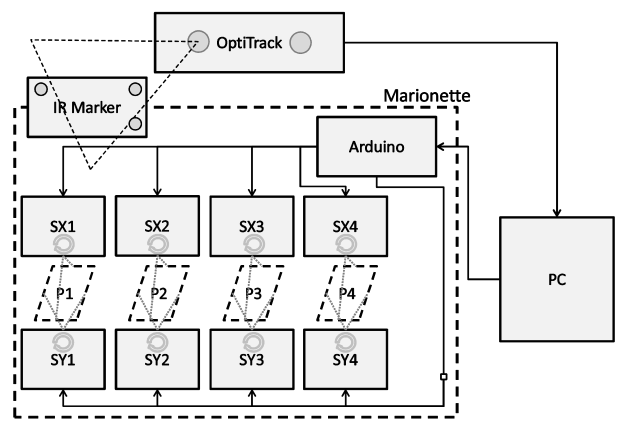


**Figure 4.** Architecture of Marionette.

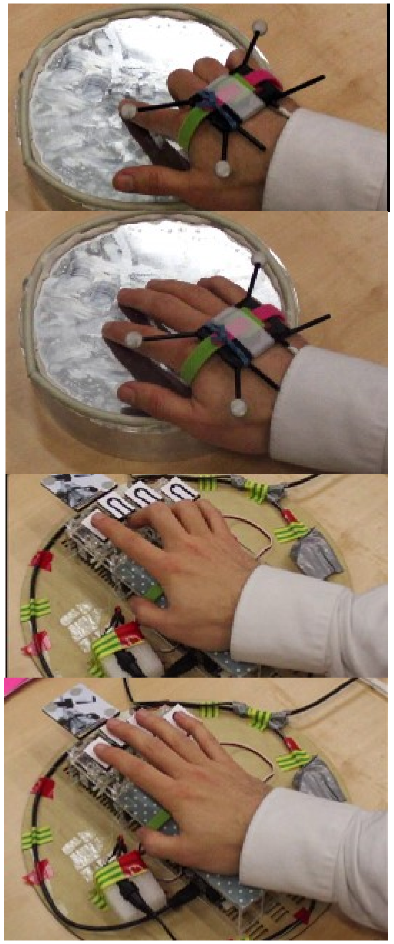

**Figure 5.** From top to bottom: 1R, 4R, 1D and 4D conditions.

A 5-point-stencil approximation is used to obtain the angles (rx and ry) at the position of each finger. Thus, having the function to be rendered [f(x,y) → height] is enough to obtain the two angles. The sample points of the approximation are rotated by the fingers rotation to get angles coherent with the rotation of the device.

Finally, the PC sends the eight servo values to the Arduino and then, the Arduino sends them to the servos. A calibration file is needed to transform from the desired rotation angles to the servo values to submit. For this process, a grid of different values was sent to both servos and the obtained angles in the plates were read by the OptiTrack. Finally, multivariate regression was used to obtain the second degree polynomials that will determine the value for each servo when a certain pair of degrees is needed: fx(rx,ry)→sx and fy(rx,ry)→sy.

The supported functions to generate haptic feedback are: analytical functions (Figure 6), depth images (Figure 7), maps (Figure 8), time dependant analytical functions (Figure 10) or live depth images from a Kinect sensor (Figure 11).

## Preliminary User Studies

Three user studies are presented; their aim is to determine factors that affect the curvature perception limit. Most of the studies and results are still to be conducted and analyzed.

All the studies have two conditions: real and device induced curvatures. In all conditions, the users were blindfolded and wore headphones with white noise to prevent hearing the servomotors or the sliding of the disks while they were changed.

In the real conditions, aluminum discs of 20cm of diameter were used as the stimulus. The discs had a plastic edge to prevent the finger from going out. Moreover, the discs where lubricated with soap to reduce friction cues.

In the device induced condition, the users had their hand on top of the device and explored the curvature by moving it. The device was mounted on a circular base and surrounded by a circle giving an equivalent exploration circled space of 20cm. The plates of the device where the users rested their fingers were also made of aluminum. The four conditions are shown in figure 5.

The procedure consisted of sitting the users in front of a table with the stimulus. Then, the user had 20 seconds to explore the first curve and afterwards another 20 seconds to explore the second curve. Finally, the user had to answer which curve was more convex. A trial consisted of a pair of curves and the given answer.

The measures per trial were the two curvatures used and the answer of the user. With this information it is possible to determine the discrimination threshold. Moreover, the remaining time from the 20 second exploration and the movements of the hand were tracked. Using the position information of the hand, it is possible to extract exploration patterns and speed or amplitude of movement. Finally, a subjective questionnaire aimed at measuring immersion and presence was used for some studies. Conditions were intertwined to counterbalance order effect.

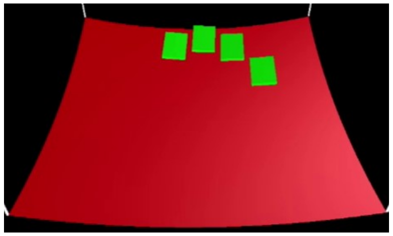

**Figure 6.** Curvature function.

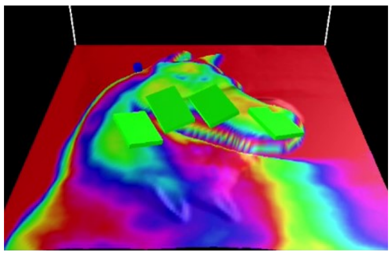

**Figure 7.** Haptic image obtained from a static depth image.

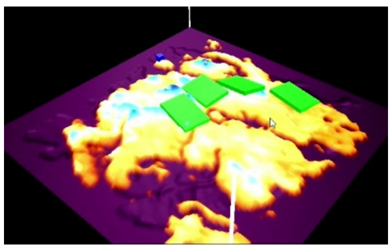

**Figure 8.** Map.

**Single-finger Real/Device (1R1D):** Does the dominance of 1st order information still holds in 2D curves discrimination? Ten participants took part (age 25.4 SD=4.3; 4 female, 6 male) in the study with 12 pairs of curves per condition. That is, 10 participants x 2 conditions x 12 pairs x 2 curves = 480 curves. Evaluation time was around 25 minutes. Pairs were created randomly combining one curve (-1.4, -0.6, -0.4, 0.4, 0.6, 1.4 $m^{-1}$) with a flat surface (0.0). Discrimination accuracy is presented on figure 9.

**4-Finger Real/Device (4R4D):** does the dominance of 1st order information still hold while using four fingers? Twelve new participants (age 28.3 SD=2.3; 5 female, 7 male) took part in the study with 36 pairs of curvatures per condition. That is, 12 participants x 2 conditions x 36 pairs x 2 curves = 1728 curves. Evaluation time was around 55 minutes. The curvature pairs were generated as in the first study. Discrimination accuracy is presented on figure 9.

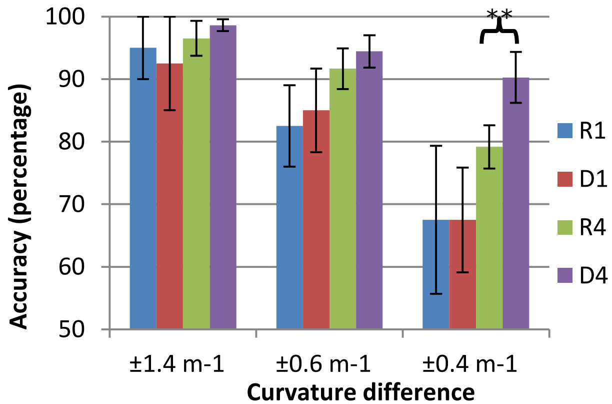


**Figure 9.** Discrimination accuracy for each curvature differences and conditions. Error bars represent standard error.

## Initial Findings

In general, accuracy decreases as the curvature difference gets smaller. Using 4 fingers always provided an improvement over using 1 finger; however, this gain was not significant. Further studies need to be conducted as they were not designed to test this.

In R1D1, no significant differences were found between the real and device condition. That is, for one finger exploration in 2D surfaces, the height information does not contribute significantly to our curvature perception. Therefore, haptic devices could focus on delivering inclination information without losing perception capabilities. Thus, cost and complexity would be reduced as complicated mechanisms to recreate height are not needed. Similar results have been reported but only for 1D curves [2][6].

In R4D4, the differences between real and device are more noticeable. Namely, for differences of ±0.4 $m^{-1}$, device was significantly more accurate than real ($t(11) = 3.370$, $p=0.006$). We hypothesized that while exploring with multiple fingers, first and second order information are more sensitive to small differences. Consequently, in this situation having zeroth order information only hinders our perception.

## Prospective User Studies

**Single/4-finger Device (1D4D):** It could be possible that multiple fingers just add redundant information as the information received by the user is the same but delayed depending on the speed of exploration. Nevertheless, multiple fingers could provide 2nd order information or decrease the mental workload. The findings will inform if the price and complexity for developing 4-finger devices are worthy.

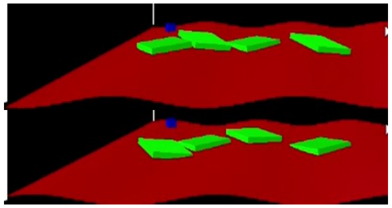

**Figure 10.** Dynamic Function.

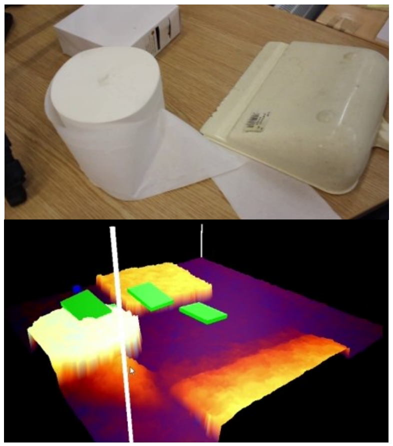

**Figure 11.** Live depth image obtained from the Kinect sensor.

**Others:** Marionette allows studying our capability to discriminate between simple shapes (squares, spheres or pyramids). Similarly, reliefs of simple objects can be represented with Marionette. Furthermore, exploration of maps would be a great advantage for visually-impaired people or an eyes-free way of exploring terrain. Finally, dynamic images could be employed to determine our capability to detect the frequency of change with our touch sense.

## Application: Ghost Touch

Ghost touch is a system that permits to haptically enhance telecommunication between two users. The haptic feedback received by each user is different. One user uses Marionette to touch the hand of the other user whereas the second one receives the haptic feedback through a focused ultrasound array modulated at 400 Hz (Figure 12). The aim of this system is to study how haptically enhanced telecommunication affects presence and immersion.

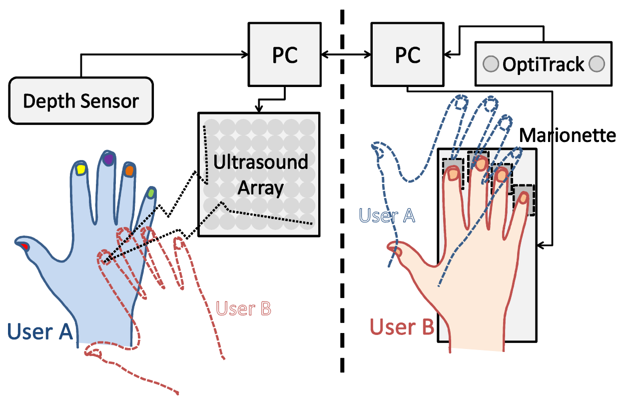


**Figure 12.** Ghost Touch Architecture.

## Conclusion

We have presented Marionette, a device that will enable a new set of haptic user studies. These studies will expand previous results of curvature discrimination to 2D surfaces and multi-finger scenarios. Moreover, discrimination of new haptic shapes such as time changing functions or maps will be analysed.

## Acknowledgements

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