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Characterizing the 3D Tracking Performance of an Haptic Device

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Abstract. Haptic devices enable blind people to interact with virtual models of objects that for location, dimension or sensitivity to damages cannot be offered to direct tactile exploration. They can increase the flexibility of this interaction and the integration and understanding of the tactile sensorial information. A realistic perception requires an effective interaction between the models of the hand and of the object through a careful and homogeneous mapping between physical and virtual spaces. This work characterizes the space mapping (useful and effective workspace and reliability of 3D tracking information) of the CyberForce used in a system for the aided fruition of 3D models by blind people. The set-up used for collecting the measures (based on a Staubli Unimation RX60) and the results obtained are presented and discussed.

1 Introduction

Haptic devices enable blind people to interact with virtual models of objects that for location, dimension or sensitivity to damages cannot be offered to direct tactile exploration. They can increase the flexibility of this interaction and the integration and understanding of the tactile sensorial information [1]. Meaningful tactile information requires a realistic geometrical and physical interaction between the models of the hand and of the object, involving a controlled and homogeneous mapping between physical and virtual spaces. Tracking the 3D position and attitude of the real hand, for driving accordingly its virtual model, must be done with a satisfactory level of accuracy: several technologies are available for reaching this results at different degrees [2]. This paper aims to characterize the performance of the CyberForce [3], by Immersion, as a mechanical 3D tracker in a system for the assisted fruition of 3D models by blind people. We need to identify the useful workspace suitable for an effective haptic interaction and the reliability of the 3D tracking information (position/attitude) inside this volume. Several set-ups have been used to acquire reliable reference values for the measure provided by the haptic arm: mechanical slides, a pan-tilt motorized head and a 6DOF robotic arm Staubli Unimation RX60 [4]. The last device has proved to be the most effective in terms of flexibility (translations and rotations with respect to all the three axes) and reliability of the provided reference values. The acquired data point out that it is possible to offer a realistic haptic interaction in a reasonably wide area with acceptable accuracy. Non-visual zoom and scrolling [5] can bring the area of interest of the model inside this region at the desired resolution, exploiting the serial nature of the tactile sense.

2 Experimental set-ups and Performance Analysis

A haptic interface is a bi-directional system that collects data from and provides feeling to a human user. Several kinds of haptic devices are available for different applications [6]. To allow blind people to explore 3D virtual models we have used the CyberForce and CyberGrasp systems, by Immersion. The former provides force feedback on the wrist and detects its position/attitude in space while the latter provides forces on the single fingers. A CyberGlove supplies the complete attitude of each finger with respect to the wrist as digital data associated to joint-angle [3]. This desktop-grounded force feedback device can apply user-programmable grounded forces to each finger and to the wrist while providing full information on position/attitude and articulation of the hand in space.

To analyze the sensory data coming from the device requires corresponding reference values: controlled translations and rotation need to be applied to the wrist. Mechanical sliders, a pan-tilt motorized head and a robotic arm with 6 DOF [4] have been used, to obtain increasing flexibility and accuracy of movements (Fig. 1).

Fig. 1 Mechanical slide (left) and a Staubli Unimation RX60, having 6 DOF (right)

The characterization of a 3D tracker requires the identification of critical parameters such as accuracy, repeatability and jitter that must be careful accounted for in developing the application to obtain a satisfactory simulation. The accuracy is related to the expected difference between the real 3D position and the data reported by the tracker [1]. The repeatability represents the radius of the sphere including all the measures associated by the tracker to the same physical position. The jitter relates to changes in the data returned while the tracked object is still in the physical world.

This study aims to define a working volume where the CyberForce satisfactorily operates as a mechanical 3D tracker, providing reliable position/attitude data. Modeling its inside this region can also enable the correction of sensory data. In our application the serial nature of tactile exploration can be exploited by associating small parts of the model to the most effective region in the physical space.

Mechanical manually controlled slides (to execute repeatable translations along the three axes) and a digitally controlled pan-tilt head (to apply rotations) have been used. The process was slow and the reliability of mechanical translations was insufficient to meaningfully estimate the accuracy and repeatability of the CyberForce. Rotations allowed to collect useful data to evaluate the data related to the pose of the CyberForce's wrist. Table 1 shows mean values and standard deviations observed by moving of different tilt angles, at varying pan angles. The repeatability of the device is 0,04° at ± 30° tilt while it is 0,09° at ± 15° tilt. The accuracy is lower than 0.5^{o}. They are compatible with the intended application.

Table 1. Measurements of angles

	15° tilt		30° tilt		-15° tilt		-30° tilt	
pan	x_m	σ	x_m	σ	x_m	σ	x_m	σ
90°	15,1687	0,0065	30,2089	0,0008	-14,8703	0,0309	-29,6118	0,0005
60°	15,1527	0,0097	30,2281	0,0003	-14,7992	0,0072	-29,5494	0,0004
30°	15,0075	0,0257	29,9824	0,0481	-14,8195	0,0476	-29,6419	0,0023
0°	14,8766	0,0060	29,7823	0,0023	-14,7572	0,0146	-29,7451	0,0024
-30°	15,1104	0,0191	30,0434	0,0019	-14,8276	0,0204	-29,6592	0,0018
-60°	15,2465	0,0943	30,2162	0,0008	-14,9178	0,0064	-29,6675	0,0004
-90°	15,2822	0,0510	30,3389	0,0368	-14,8703	0,0309	-29,7329	0,0002

Table 2. Measured displacements in cm at a distance respectively of 37 cm, 42 cm, 47 cm, 52 cm and 57 cm along z axis from the origin of CyberForceGrasp's coordinate system

Dist. 37 cm	5 cm left	10 cm left	15 cm left	5 cm right	10 cm right	15 cm right	10 cm back	15 cm back	10 cm up
x_m	4,610	9,722	14,881	4,614	9,722	15,002	10,298	15,431	10,216
σ	0,030	0,097	0,131	0,083	0,015	0,018	0,009	0,005	0,009
Dist. 42 cm	5 cm left	10 cm left	15 cm left	5 cm right	10 cm right	15 cm right	10 cm back	15 cm back	10 cm up
x_m	4,671	9,775	14,912	4,711	9,828	15,087	10,256	15,427	10,273
σ	0,009	0,111	0,016	0,013	0,018	0,112	0,009	0,001	0,003
Dist. 47 cm	5 cm left	10 cm left	15 cm left	5 cm right	10 cm right	15 cm right	10 cm back	10 cm up	
x_m	4,718	9,814	15,087	4,763	9,896	15,154	10,256	10,330	
σ	0,011	0,101	0,058	0,012	0,090	0,106	0,011	0,007	
Dist. 52 cm	5 cm left	10 cm left	15 cm left	5 cm right	10 cm right	15 cm right	10 cm back	10 cm up	
x_m	4,756	9,889	15,151	4,794	9,934	15,208	10,238	10,351	
σ	0,011	0,098	0,089	0,013	0,086	0,101	0,009	0,007	
Dist. 57 cm	5 cm left	10 cm left	15 cm left	5 cm right	10 cm right	15 cm right	5 cm back	10 cm up	
x_m	4,789	9,956	15,257	4,835	9,964	15,212	5,060	10,363	
σ	0,011	0,094	0,059	0,012	0,014	0,001	0,007	0,009	

The translations have been repeated by connecting the wrist of the CyberForce to the end-effector of the Staubli (Fig. 1). At different positions in the workspace, several translations, along the three axes, have been repeated to provide a meaningful estimation of the desired parameters (Tab. 2). Both mean values and standard deviations for translations along the y axes (from bottom to top) and z axis (from back to ahead) stay practically constant at every z. It is important to map the virtual model in the physical space at a distance z near 50 cm to optimize perception of its dimensions. The accuracy increases with the distance from the origin of the haptic coordinate system: mean errors and standard deviations on horizontal movements along x axes (from left to right) decrease as the distance z increases (Tab. 3).

Table 3. Error for translations along the three axes and for horizontal translations at different distances from the origin of CyberForceGrasp's coordinate system

Distance along z [cm]	37	42	47	52	57
Total error	0,266	0,238	0,204	0,196	0,168
Horizontal error	0,241	0,198	0,178	0,164	0,142

3 Conclusions

This work aims to characterize the CyberForce, by Immersion, as a 3D tracker in a system for the aided fruition of 3D models by blind people. In particularly we identify the workspace suitable for an effective haptic interaction and the reliability of the 3D tracking information inside this volume. Experiments show that the accuracy and repeatability of the device are not homogeneous with respect to the distance from the base of the haptic device. The analysis points out that rotations are reliably estimated. Some errors may occur on translations especially in the region closer to the origin of the reference system: they become smaller at a distance of about 50 cm from the origin. At closer distances, corrections may be needed by suitably modeling the mean error. These results still allow the use of the device for the intended application, where the serial nature of the tactile exploration allows to propose the part of interest of the virtual model in the region of the physical space where the CyberForce provide its better performance.

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