How do you choose a haptic device?

As you begin your search for a haptic device, you'll be looking at various specifications of the devices. But what do all those terms mean? The goal of this document is to explain the terms and present the psychophysical evidence that exists to help you decide what is necessary in a haptic device.

Inertia: This is a measure of the mass of an object. It is important that the haptic device have the lowest inertia possible in order to increase the transparency of the device. In other words, a haptic device needs to communicate between the real and virtual world without introducing extra forces. Translational inertia can be measured in grams, while rotational inertia is expressed as mass times a distance squared ($g \cdot cm^2$).

Backdrivability: The ability to move the end-effector in the workspace without opposition. The device should ideally produce no forces on the user's hand when there is no interaction with an object in the virtual world. A device's backdrivability is usually characterized by backdrive friction (N). There are certain elements that reduce backdrivability, such as gears and friction in the motors and their transmissions. It is possible to have different values for each degree of freedom, especially in rotation and translation motions.

Friction / Damping: Kinetic friction comes in two varieties – *Coulomb friction*, which is independent of velocity, and *viscous friction* (or damping) which is proportional to velocity. Both Coulomb friction and damping can be considered as resistance to free movement. These are forces that always oppose the motion. If sufficiently high (greater than the human tolerance), they will degrade the force transferred to the user and thus the fidelity of the machine. Coulomb Friction is measured in N, but damping is usually reported as a coefficient in N·s/m or kg/s (such that when it is multiplied by velocity (m/s) a force in Newtons is the result).

Maximum Exertable Force: The maximum force that the actuators can exert. It may be over a time period of several milliseconds, allowing a momentary tap or touch on a hard object.

Continuous Force: The amount of force that the hand controller can exert for an extended period of time.

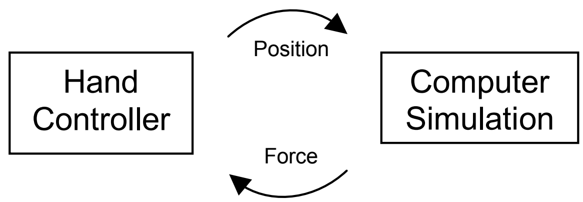
Minimum Displayed Force: The ability of a hand controller to display slight forces is a result of its low friction and its precise motor control.

Dynamic Force Range: The ratio of the maximum displayable force to the minimum displayable force. The wider the range, the greater the ability of the device to display a wide variety of forces and torque in a virtual environment.

Stiffness: The ability of the hand controller to mimic a solid virtual wall. It has been reported that stiffness needs to be 25 N/mm in order to feel stiff to a user when vision is obscured (Tan et al., 1994). However when the optical system is not obstructed this value can be lower. Dynamic range is important in showing a range of stiffness values.

Position Resolution: The smallest amount of movement over which the sensors can detect a change of position (Hayward and Astley, 1996). Good position resolution is one factor in displaying stiff virtual walls without vibration.

System Latency: The total time lag of the components in the hand-controller – computer system. The inverse, the update rate, is more often quoted. The complete loop consists of position from the device, computation of force in the simulation, force sent to the device, and the next device position read. It may be characterized by the time delay between successive commands sent to the hand controller. This time will vary according to the speed and quality of the computer.



Device Latency: The time delay between sending a command to a device and receiving a response from that device. This would normally include geometrical computations (the forward and inverse kinematics), some of which may take place in the computer.

Update rate: The speed at which the feedback loop can be completed, measured in Hz.

Bandwidth: The frequency range over which the hand-controller provides feedback. The range needed will depend on the operation being performed. Generally, small, precise movements will require a higher frequency feedback than large, more powerful movements. For example, tactile sensing requires the highest frequency (100-1000 Hz), while kinesthetic and proprioceptive sensing requires a bandwidth of 20 to 30 Hz. The response bandwidth required by the hand and fingers to exert force is much lower, being between 5 and 10 Hz. (Burdea, 1996)

Fidelity: The ability of the simulator to simulate real-world interactions. A high-fidelity device has high sensor resolution, good actuator performance, low computer latency and near-ideal transparency in the transmission of the forces.

Backlash: This is characterized by moving the end-effector without a corresponding position being sensed. It feels like a dead-zone or void in space that occurs when you move the end-effector in one direction against an opposing force, then switch to another direction where no force opposes the motion. It is often associated with gear systems where it is defined as the excess space between the interfacing teeth.

Maximum Acceleration: Important for emulating stiff walls. This may be measured by accelerometers attached to the hand controller.

Precision and Repeatability: Precision refers to how well a sensor can detect its position. Repeatability refers to how accurately it can sense the identical position as being the same position.

Workspace: The volume (or area) that the hand controller can reach is reported as the workspace. Often the workspace changes with different configurations of the robotic device, and is therefore quoted as the dimensions of an ellipsoid. Note that the workspace should be quoted as the volume over which the full rotation of the handle is maintained. With some devices, handle rotation may be restricted towards the limits of the translational workspace.

Translational workspace is the volume traversed in Cartesian coordinates.

Rotational workspace is the angle range in pitch, yaw and roll.

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The workspace should be chosen according to the intended range of motion of the user's hand. This is determined in part by the intended fulcrum point – will the user rotate about the side of the hand, or the wrist, the elbow or the shoulder? More accurate motions, such as handwriting, are usually executed with the side of the hand resting on a surface.

What is your intended application?

As you may have realized in the specifications, you have to know what you need in order to determine what you're willing to trade-off. For instance, if you want a haptic device to produce high forces, it will not in general be capable of producing very precise, small forces. It will also be stiffer, with higher friction and inertia values. However, if you need to perform the delicate, precise movements of a neurosurgeon, you have to sacrifice high force (which is probably not required anyway) for a low friction, low inertia machine.

Figuring out how good is good enough for your application is very difficult if you don't have a good idea of how humans perceive touch. Check out the human factors section to learn more http://www.mpb-technologies.ca/mpbt/haptics/hand_controllers/freedom/f6_resources.html.

References

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