PHANTOM™ PREMIUM

User's Guide

Bringing 3D Touch™ to Your Desktop

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SensAble technologies

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Introduction

Congratulations on your purchase of a PHANTOM ***PREMIUM***, a member of the award-winning PHANTOM line of 3D Touch™ systems. It will enable you to interact with 3D computer data and models in an entirely new, dramatically more intuitive and productive way – using your sense of touch.

- This manual will guide you through the installation and setup of your PHANTOM ***PREMIUM***. If you encounter any difficulties, please contact Customer Support as indicated in Appendix A of this document.

We also invite you to visit our Web site at www.sensable.com to learn more about:

- SensAble's 3D Touch technology
- 3D Touch-enabled applications and software products from SensAble and other vendors
- Artists, engineers, medical professionals, data analysts and other 3D professionals who are revolutionizing the quality, productivity and satisfaction of their work through 3D Touch
- Haptics resources for researchers and developers

Caution

The PHANTOM ***PREMIUM*** device must be installed in accordance with the applicable requirements.

It is important to exercise care when working with force feedback devices:

- Read the manual thoroughly prior to using your PHANTOM ***PREMIUM***

  - DO NOT put your face in the workspace of the PHANTOM ***PREMIUM***. Safety glasses are recommended.
  - DO NOT place your fingers inside the mechanism. At the installation site, access to motors and pulleys should be prevented.
- As a user of this product and software, you accept full responsibility for assuring that the device is used in a safe and reasonable manner.

Table of Contents

Preface

About This Guide

The PHANTOM ***PREMIUM*** User's Guide describes the process of installing the hardware, required device drivers, and demonstration software for your new PHANTOM ***PREMIUM*** system. It also provides descriptions of several demonstration programs that highlight the capabilities of the GHOST® SDK.

We've worked extensively to ensure that the PHANTOM ***PREMIUM*** & Device Drivers install and work smoothly on your computers. If you experience any problems in the installation or use of your system or hardware, please contact technical support as indicated in Appendix B of this document. Your feedback and input are essential! Please don't hesitate to contact us with technical questions and suggestions for improvement.

How This Guide Is Organized

The PHANTOM ***PREMIUM*** User's Guide is divided as follows:

- ***Chapter 1: Getting Acquainted*** describes the PHANTOM ***PREMIUM*** and many of the items that came with the system.
- ***Chapter 2: Installing the PHANTOM Device Drivers*** describes how to install the software necessary to run this product on Intel (and some AMD) processor PCs under Windows NT 4.0, Windows 2000, Windows XP and on RedHat Linux 7.2.
- ***Chapter 3: Installing the PHANTOM PREMIUM*** describes how to connect the hardware.
- ***Chapter 4: Computer Setup for Windows*** describes changes that may need to be made to your computer for using the PHANTOM ***PREMIUM*** device via the parallel port.
- ***Chapter 5: Running the Demos*** describes several demonstrations to illustrate the power of 3D Touch and the ***GHOST*** SDK.

The PHANTOM *PREMIUM* User's Guide uses the following conventions:

Typographical

Italic indicates terms or concepts, and shows emphasis. It also indicates cross-references to related publications or chapters in this guide.

Bold is used to indicate directory paths or program group names.

`Monospace` identifies code samples. It may also appear to indicate text you can or must enter to perform a particular action.

Special fonts are used to indicate SensAble Technologies products: GHOST, PHANTOM, and ***PREMIUM***.

A **NOTE:** is used to highlight important additional information.

System Requirements

The following system requirements apply to the use of the PHANTOM ***PREMIUM*** and driver software:

- The PHANTOM ***PREMIUM*** and Device Drivers run on Intel (and some AMD) processor PCs under Windows NT 4.0, Windows 2000, Windows XP and on RedHat Linux 7.2.
  - Many AMD motherboards will not support the PHANTOM. We have had the most success with the AMD MPX-based motherboards. We recommend using Intel processors and motherboards.
- When PCs are used, it is recommended that you use a 300 MHz Pentium processor at minimum. A dual-processor machine is highly recommended.
- The PHANTOM Device Drivers distribution requires approximately 30 MB of disk space. The PHANTOM Device Drivers *do not* specify memory requirements; however, a minimum of 32 MB is recommended.
- The PHANTOM Device Drivers are distributed on CD-ROM both separately and on the same CD as the GHOST SDK. Distributions are available for Windows NT, Windows 2000, Windows XP and RedHat Linux 7.2 platforms.

Chapter 1: Getting Acquainted

"*In the early days of the phonograph people were amazed to hear a voice coming out of a box, and everyone was working to build devices with better sound quality. But once the fidelity improved, content became the interesting issue, and the focus shifted to the music. Before the* PHANTOM*, force feedback research was mostly concerned with designing new mechanical interfaces with better 'feel'. The* PHANTOM *is such a quantum leap in fidelity and ease of use that now computer scientists, designers, physicians, psychologists, even artists can focus on incorporating feedback in a wide range of new applications".*

–Dr. Robert Howe, Harvard University

This chapter describes the PHANTOM ***PREMIUM*** and the other contents that were shipped with the product.

Description

The PHANTOM ***PREMIUM*** enhances productivity and efficiency by enabling the most intuitive human/computer interaction possible, the ability to solve problems by touch. The PHANTOM system has been widely recognized as the finest 3 degree-of-freedom (3DOF) force-feedback device available. It is unlike any other haptic device in that it offers realistic 3D Touch™ technology, the ability to feel the properties of virtual 3D objects, with higher fidelity and lower cost than other force feedback devices.

For the first time computer-generated objects can be created, manipulated, and deformed just like their real counterparts in the most natural way possible...by hand. Mechanical engineers can perform maintenance analyses and check tolerances of virtual assemblies, model makers can sculpt virtual digital mockups, molecular chemists can fit drug molecules into virtual human receptor sites, surgeons can practice on virtual patients, all digitally, but with an incredible sense of realism.

PHANTOM *PREMIUM*

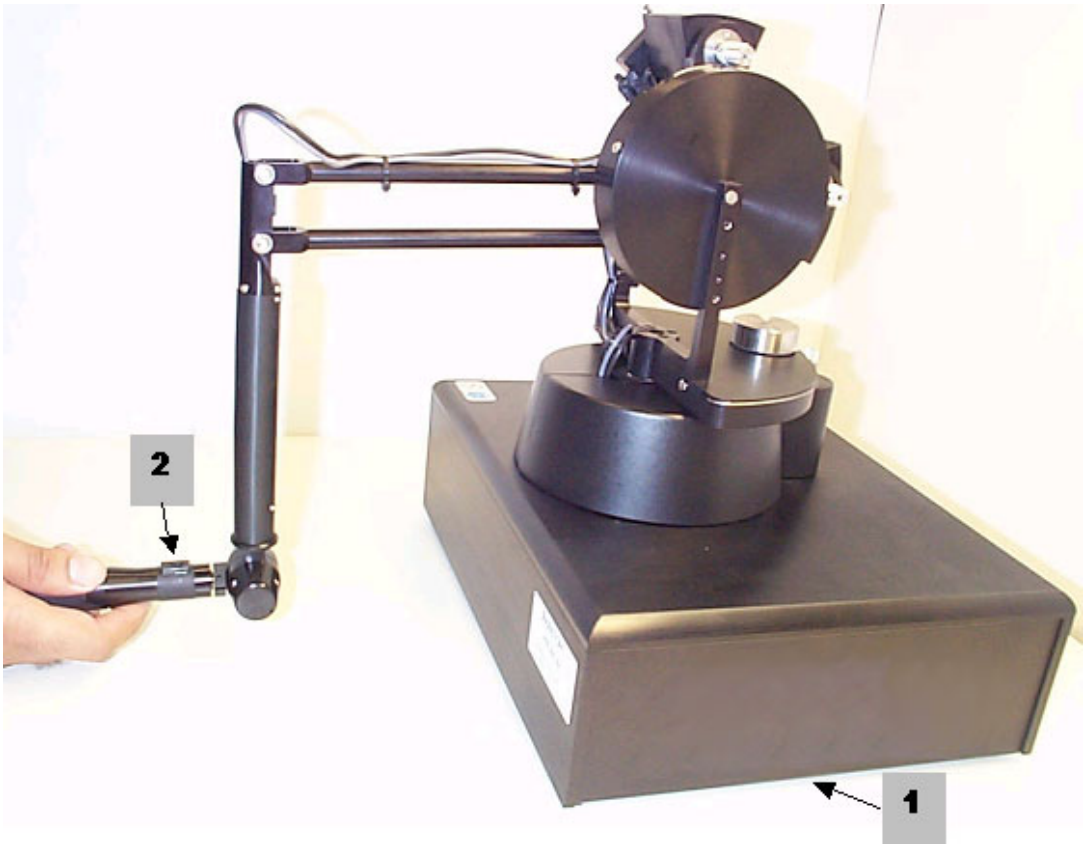


*Figure 1: PHANTOM **PREMIUM** (1.5/6DOF Model shown)*

1. PHANTOM ***PREMIUM*** lifting points

   The PHANTOM PREMIUM is a sensitive piece of electronic equipment. Lift by placing your hands under the bottom of the base, and support the base when moving it (Box 1). Lifting by any of the moving parts may affect the unit's performance and risks damaging the device.

2. **Stylus with Switch:** The stylus is the "handle" or "pen" you use to interact with virtual objects (Box 2). Your forefinger or thumb should rest above the raised switch when using the device. Like a mouse button, the switch is used differently in each application.

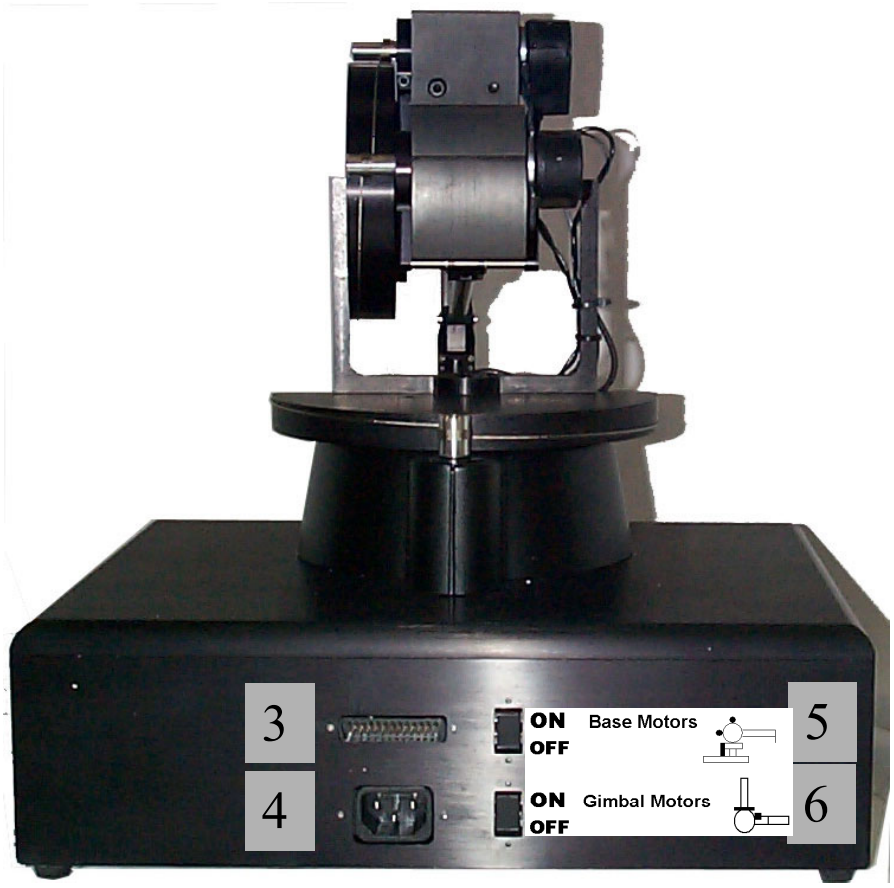
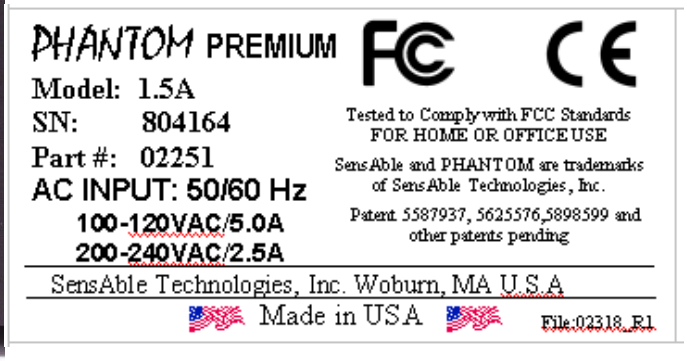


Figure 2: Connectors and switches on the rear of the PHANTOM ***PREMIUM 1.5/6DOF***

3. **Parallel Port To Computer:** The male bottom connector is connected to the computer's parallel port using the supplied IEEE-1284 rated cable.
4. **AC Power Plug:** The AC Power Plug is connected to the wall outlet with a power cord. The integral switching power supply in the base of the device works for both 115V and 230V AC supplies.
5. **Motor power switch for base motors (1.5/6DOF Only):** The first motor power switch is used to cut off the power to the three base motors which are responsible for translational force feedback. When the switch is in the "ON" position the motors and encoders are both connected. When the switch is in the "OFF" position, the encoders are still powered but the motors are not. This is a handy feature for debugging new haptics code.
6. **Motor power switch for gimbal motors (1.5/6DOF Only):** The second motor power switch is used to cut off the power to the three gimbal motors which are responsible for rotational torque feedback. When the switch is in the "ON" position the motors and encoders are both connected. When the switch is in the "OFF" position, the encoders are still powered but the motors are not. This is a handy feature for debugging new haptics code.

PHANTOM *PREMIUM* Rear View

Figure 3: PHANTOM ***PREMIUM*** *rear interface with auto-switching power supply and label close-up*



Other Items

- **Parallel Port Cable:** The cable is used to attach the computer's parallel port to the PHANTOM ***PREMIUM***. The cable is an IEEE 1284 EPP cable with a ferrite bead that provides an impedance at 100mhz of 199 ohms or greater.
- **PHANTOM Device Drivers CD:** This CD includes all of the drivers needed to set up and run the PHANTOM ***PREMIUM*** as described in the next sections. Demos are also provided on the CD. (If you also purchased the GHOST SDK, then the PHANTOM Device Drivers will be found on that CD instead.)
- **Power Cord**: The power cord connects the PHANTOM ***PREMIUM*** to the wall outlet. If no cord was shipped with your unit, use a cable with a current carrying capacity of at least 5 Amps that satisfies national and local electrical requirements.

***NOTE:** Your box may also include other SensAble Technologies software purchased with your order.

Chapter 2: Installing the PHANTOM Device Drivers

This and the following sections will show you step by step how to install the PHANTOM ***PREMIUM***. First you will install the software on your computer. Then**, while the computer is off**, you will setup the PHANTOM ***PREMIUM*** and plug in all of the cables. When you restart the computer, you will configure the parallel port in the computer's BIOS setup (Windows only). You will then be able to run all of the demos provided on the CD and try your PHANTOM ***PREMIUM*** for the first time.

Installing on Windows NT/Windows 2000/Windows XP

To install the PHANTOM Device Drivers on a Windows NT/2000/XP platform:

1. Log in to your computer as administrator (or as a user with administrative privileges).
2. Insert the CD into the CD-ROM drive. Then run **SETUP.EXE** from the PHANTOM Device Drivers folder. Follow the instructions on the screen during the installation to specify the installation directory and custom installation instructions.

   If you have previously installed an older version of the PHANTOM Device Drivers on the computer, you will be prompted to remove it before proceeding with the installation. If you get this message, exit the setup program. Then go to the Start menu in Windows and select Settings → Control Panel → Add/Remove Programs. Find PHANTOM Device Drivers in the list and select it. Then hit the Add/Remove button and follow the on screen directions.

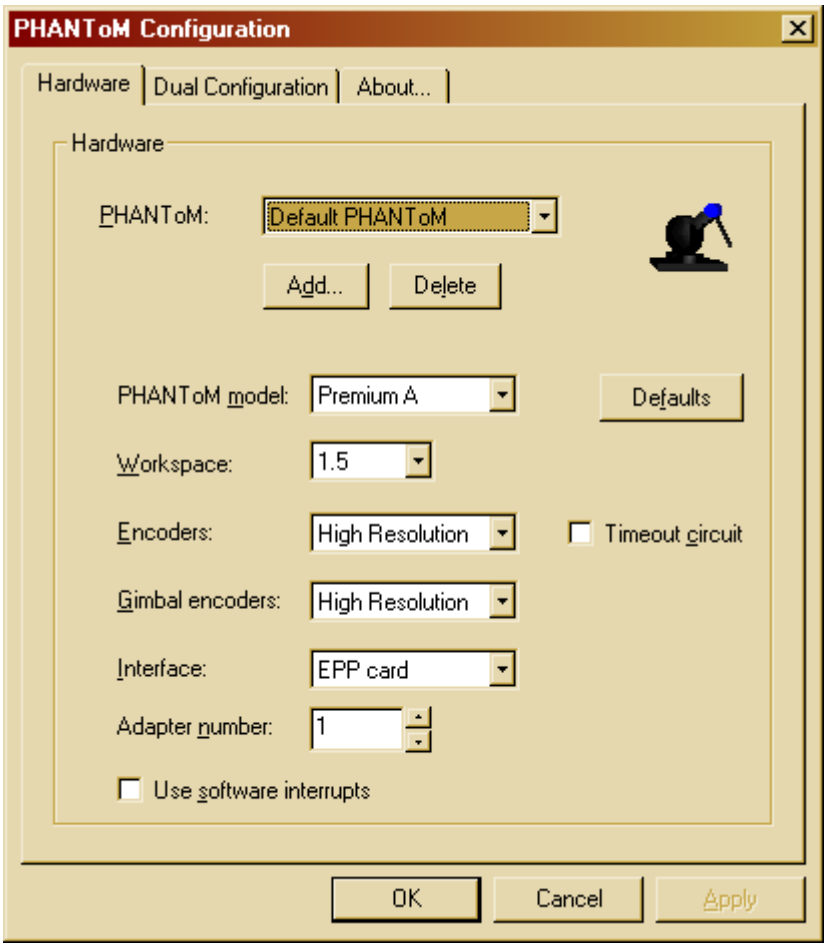
   NOTE: If you are prompted during the uninstall to delete shared files that appear to no longer be needed, DO NOT DELETE these files unless you are absolutely sure of their use.

   When you have finished uninstalling, resume the installation of the new PHANTOM Device Drivers.

   The default directory for installing the PHANTOM Device Drivers is **C:\Program Files\SensAble\PHANTOM Device Drivers**. You can find demo program executables in the **C:\Program Files\SensAble\3D Touch Demos** directory. Demo programs also are available from a **3D Touch Demos** program group, found in the Start Menu.

   At the end of the Setup process you will be presented with a dialog box to allow you to configure the software for your PHANTOM ***PREMIUM***.

3. Configure the PHANTOM ***PREMIUM*** using the dialog box below:



[You can also access the PHANTOM Configuration application any time after installation through the Settings/Control Panel/PHANTOM Configuration icon from the Start Menu.]

Figure 4: Selecting the Configuration

[NOTE for users of older GHOST SDK versions: "Reconfigure for a Different PHANTOM" is no longer used with the PHANTOM Device Drivers for NT, and hence, is not available through the Start Menu.]

Select the "Default PHANToM" item from the **PHANToM** pull-down list.

Specify the correct PHANTOM ***PREMIUM*** in the **PHANTOM Model** field. Specify the proper workspace size (1.0 for the 1.0A model, 1.5 for the 1.5A or 1.5/6DOF models).

For a 1.0A or 1.5A, select the EPP card option from the **Interface** field. For the 1.5/6DOF, the interface will default to **Parallel port**; no other interface type is supported.

Ensure that **Timeout circuit** is not checked.

The "**Use software interrupts**" should only be used when using a PCI-based add-in

parallel port card. It should be selected only if normal interrupts are not working.

The **Port Mode** allows settings of either ECP or EPP. (Windows 2000/XP will auto-detect this setting along with the **Base Address**. If you are using Windows 2000/XP you can skip to step 4 below).

If you are using Windows NT, find your computer in the list below and set the Port Mode to the setting listed for it in its Port Mode column. If your computer is not listed, then select ECP.

Company	Model	Port Mode
Compaq	AP500, SP700, SP750	ECP
Dell	Precision 410/420/620 Dimension 4100	ECP
Gateway	GP & E-5400	EPP
HP	Kayak XU800	EPP
HP	Kayak XA450	ECP
IBM	Intellistation Mpro	EPP
Micron	PowerDigm	ECP

The **Base Address** field is used to specify the address of the parallel port that will be used by the PHANTOM ***PREMIUM***. In most cases, this will be 0x378. If you have installed an additional parallel port card for use with your PHANTOM ***PREMIUM***, you will need to check your system settings to determine the correct values. For an add-on card, this value will most likely be 0x278.

4. After the installation completes you will be prompted to restart the computer**. DO NOT RESTART THE COMPUTER**. Choose to restart later.
5. If you are planning to install GHOST SDK you should install it now. For instructions on installing GHOST SDK see the GHOST SDK Programmers Guide.

Installing on RedHat Linux 7.2

These instructions assume that GHOST and the PHANTOM Device Drivers for Linux have been installed according to their instructions.

1. Obtain the IRQ and IO port address information for the parallel port to which the PHANTOM is connected. This can be found under Windows or from the BIOS. Your BIOS settings may also need to be adjusted.
2. Add the following line to your /etc/modules.conf file (this example assumes that the IRQ is 7 and the IO Address is 0x378)

```
options parport_pc io=0x378 irq=7
```

3. To enable these options, run

```
modprobe -r parport_pc
```

```
modprobe parport_pc
```

4. Finally, run PHANTOM Configuration and configure your PHANTOM as the appropriate device (6DOF, 1.0A, etc.).

   To run PHANTOM Configuration, type:

```
PHANToMConfiguration
```

   A ***PREMIUM*** 1.5/6DOF should be configured as follows:
   PHANTOM Model: 6DOF
   Workspace: 1.5

   A ***PREMIUM*** 1.0A or 1.5A should be configured as follows:
   PHANTOM Model: Premium A
   Workspace: 1.0 or 1.5
   Encoders: High Resolution
   Gimbal Encoders: None or High Resolution (if the encoder gimbal is installed)
   Interface: PCI (this will be explained momentarily)
   Adapter Number: 1

5. If you are configuring a 1.5/6DOF, it is now ready to be used. If using a ***PREMIUM*** 1.0A or 1.5A, you will need to open the configuration file for this PHANTOM (likely /etc/SensAble/PHANToM Device Drivers/Phantom0.ini) and change the line reading "PCI" to read "EPP".

Chapter 3: Connecting the PHANTOM *PREMIUM*

To connect a PHANTOM ***PREMIUM*** to your computer:

Lift by the metal covers and support the base when moving the *PHANTOM* ***PREMIUM. Lifting by any of the moving parts may affect the unit's performance and risks damaging the device.***

1. Attach the male end of the supplied IEEE-1284 rated cable to your computer's parallel port.

   The high demands of the PHANTOM ***PREMIUM*** on the parallel port require the PHANTOM ***PREMIUM*** to have a dedicated parallel port for its use. If you are currently using your parallel port for a printer, dongle or other peripheral, you will need to install an additional parallel port card in your system. You can choose whether to connect the PHANTOM ***PREMIUM*** or the other peripherals to the additional card.

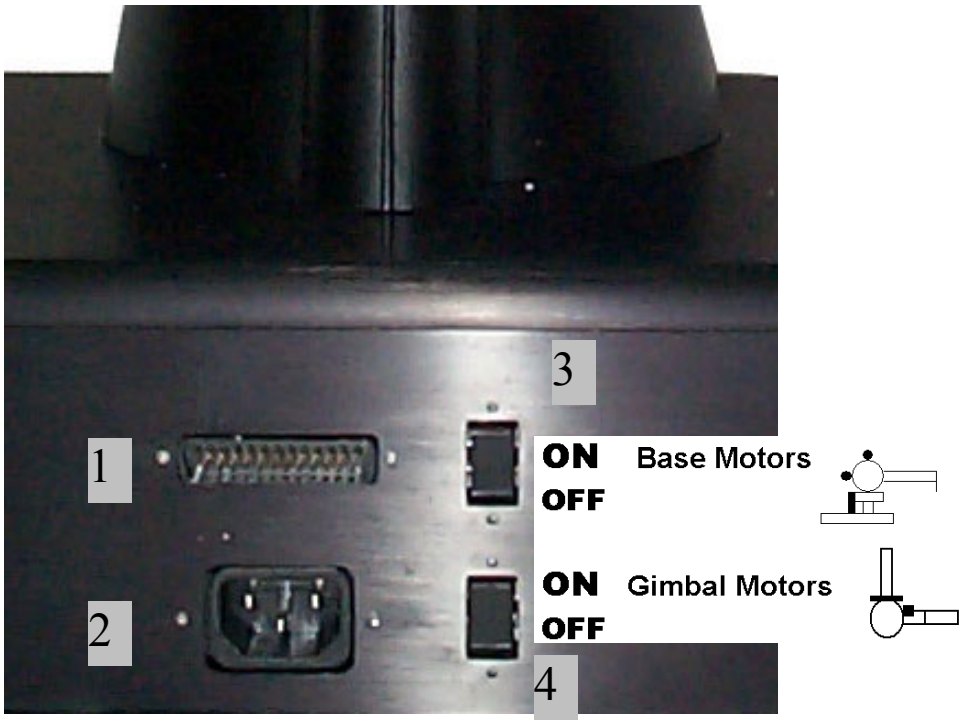


Figure 5: Detail of Connectors

2. Plug the female end of the cable to the male connector (Item 1) of the PHANTOM ***PREMIUM***.
3. Plug the power cord into the AC power socket (Item 2) of the PHANTOM ***PREMIUM***.

4. (Plug the power cord into an available outlet (for 110V the outlet must be rated for at least 2 Amps, for 220V: 1 Amp).
5. Leave the Gimbal and Base motor switches (Items 3 and 4) in the "ON" position for normal operation. These switches can be used to cut off motor power for debugging purposes. (1.5/6DOF model only).
6. Position the PHANTOM ***PREMIUM***

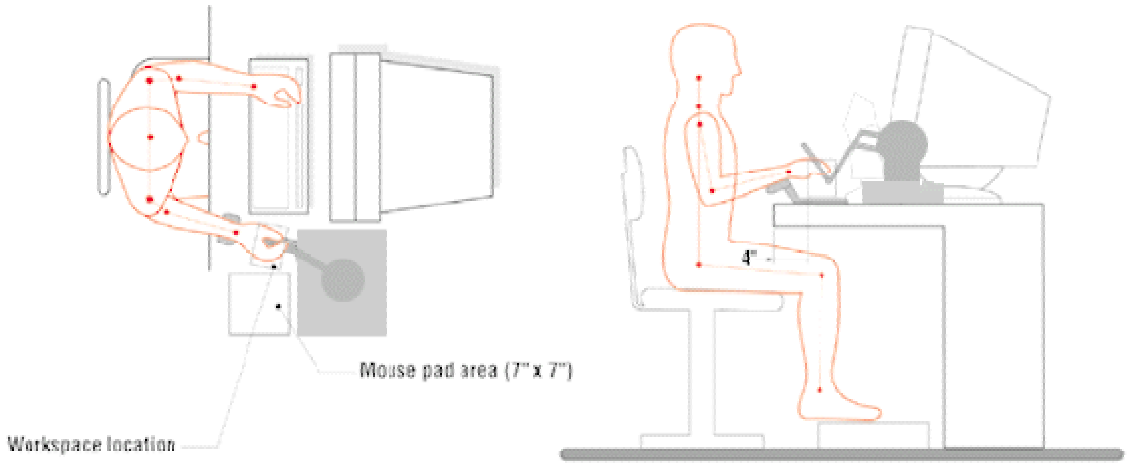


Figure 6: Suggested Position of the PHANTOM ***PREMIUM***

Place the PHANTOM ***PREMIUM*** to the inside of your mouse. This should place the device in a comfortable position. The PHANTOM ***PREMIUM*** can be used in place of the mouse in certain applications. For information on how to create an application that includes PHANTOM mouse behavior, see the GHOST Programmer's Guide.

Now that the PHANTOM ***PREMIUM*** is properly positioned, you may continue with the final steps of installation and check out. If you are installing on Windows, proceed to Chapter 4: Computer Setup for Windows.

Chapter 4: Computer Setup for Windows

Depending on your computer, you may have to configure your System's BIOS for communicating to the parallel port via the ECP or EPP communication protocols. Find your system in the table below:

List A **(no change in BIOS required)**	**List B** **(change to BIOS required)**
Compaq AP500, SP700, SP750	Dell 4100 (Delete Key)
Dell 410, 420, 620	Gateway E-5400 (Enter Setup)
HP Kayak XA450	Gateway GP Workstation (F1)
	Micron PowerDigm (F2)
	HP Kayak XU800 (F2)
	Intellistation Mpro (F1)

If your computer appears in List A, then no change is required; you can turn on your computer and skip directly to Chapter 5. If your computer appears in List B or is not listed, then you will need to reconfigure your computers BIOS as explained below.

To change the BIOS settings:

1. Turn on your computer and get ready to enter BIOS setup. On most systems, a message such as "Hit F2 for Setup" will appear shortly after power-up. The most common key to hit for your system is listed in the table above in parentheses in the List B column. However, you should double-check your computer manual to be sure what key to hit and when.
2. Enter the peripheral setup options.

   Once you have entered the BIOS setup, you need to access the BIOS page for configuring peripherals. On most systems, these options are presented in the **advanced** page or a **peripheral** page of the BIOS setup.
3. Set the parallel port to the correct mode (ECP or EPP) by setting it to the value listed for your computer in the table below.

List B (Change to BIOS Required)	**Set Port Mode To**
Dell 4100	ECP
Gateway E-5400	EPP
Gateway GP	EPP
Micron PowerDigm	ECP
HP Kayak XU800	EPP
Intellistation Mpro	EPP

If your system is not listed or does not have an ECP or EPP setting, please contact Customer Support as indicated in Appendix B of this document.

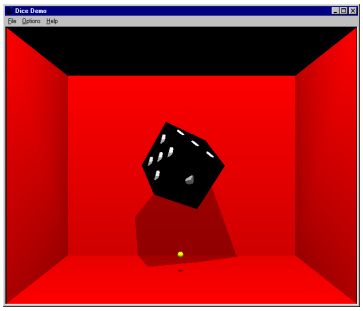
4. Save your changes and exit the BIOS setup. This will reboot your system automatically.
5. When back into the operating system, run the PHANTOM Configuration Control Panel a second time. This will force the drivers to re-detect the parallel port mode.
6. Your computer should now be set up for working with the PHANTOM ***PREMIUM***

Chapter 5: Running the Demos

This chapter describes several demo programs you may want to run to illustrate some of the power of your PHANTOM ***PREMIUM*** and the GHOST SDK.

On Windows, the demos are accessible in the **3D Touch Demos** program group from the Windows Start Menu. On a Linux workstation, the demos are located in the **/usr/bin** directory.

Dice



The Dice demo is currently the only demo that specifically demonstrates the functionality of the 1.5/6DOF device. The Dice demo consists of a single cube bounded by a box-shaped haptic workspace. This program makes use of more advanced dynamics and collision detection. There are options for enabling/disabling gravity, adjusting dynamic properties of the cube, and if you click the stylus while touching the cube, you can pick it up. Resistance to translation is experienced as the dice is pushed against any of the walls in the box. Resistance to rotation is experienced as the dice is rotated while remaining in contact with at least one wall.

See *Appendix G: Dice Demo Notes*, for more information.

All the other demos will run with the 1.5/6DOF, but will only display forces in three degrees of freedom.

Blocks

The Blocks program consists of two cube objects located inside a box-shaped haptic workspace. The objects have simple three-dimensional dynamics and collision detection. There is an option for enabling/disabling gravity.

Lump

In the lump demo there is a kidney that you can feel. If you touch the kidney and then push harder, you can push through into the interior of the kidney, where the material will feel viscous. Inside the kidney there is a spherical tumor. Search for it just by using your sense of touch. When you find it, if you touch it and press and hold the stylus button you can drag the tumor out of the kidney. You can also use the stylus on the PHANTOM device to orient the model by holding down the "g" key on the keyboard and the stylus button at the same time.

Effects

The Effects program demonstrates some of the different force effects in the *GHOST SDK* such as buzzing, constraints and inertia.

TouchVRML

The TouchVRML demo allows you to see and touch VRML 2.0 files which contain triangular meshes. A number of sample files are provided in the TouchVRML directory.

[TouchVRML is not provided on Linux. Instead there is a hapticViewer program which lets you see and feel VRML files.]

WorldBuilder

World Builder is an interactive scene editor. It lets you create touchable objects by combining different basic shapes. In addition to setting the color of any of the shapes you can also set the stiffness and friction for an object. Scenes created with World Builder can be saved and reloaded. A set of sample scenes is provided as well as full source code.

Further documentation on World Builder can be found in the same directory as the World Builder executable.

[World Builder is not provided on Linux. Instead there is a WorldViewer program which lets you see and feel files created with World Builder but not edit them. To use WorldViewer you should specify the name of the file to read as a command line argument.]

Dual PHANTOM

This program is identical to Blocks except that it allows you to use two `PHANTOM` devices at once. The two devices should be facing each other and there should be six centimeters between the gimbal endpoints when the devices are in the reset position. See *Appendix D-1* for more information on configuring for this setup.

Initialization position

The PHANTOM ***PREMIUM*** must be started in the neutral position. At this position, the thin "hamstring" linkage is horizontal, and the "shin linkage is vertical. The switch button on the handle points up and the handle itself is horizontal. The 1.5/6DOF gimbal should be oriented according to its marked RIGHT and LEFT, while the 1.0A and 1.5A gimbal (if installed), should be oriented as marked with the proper side facing the PHANTOM.

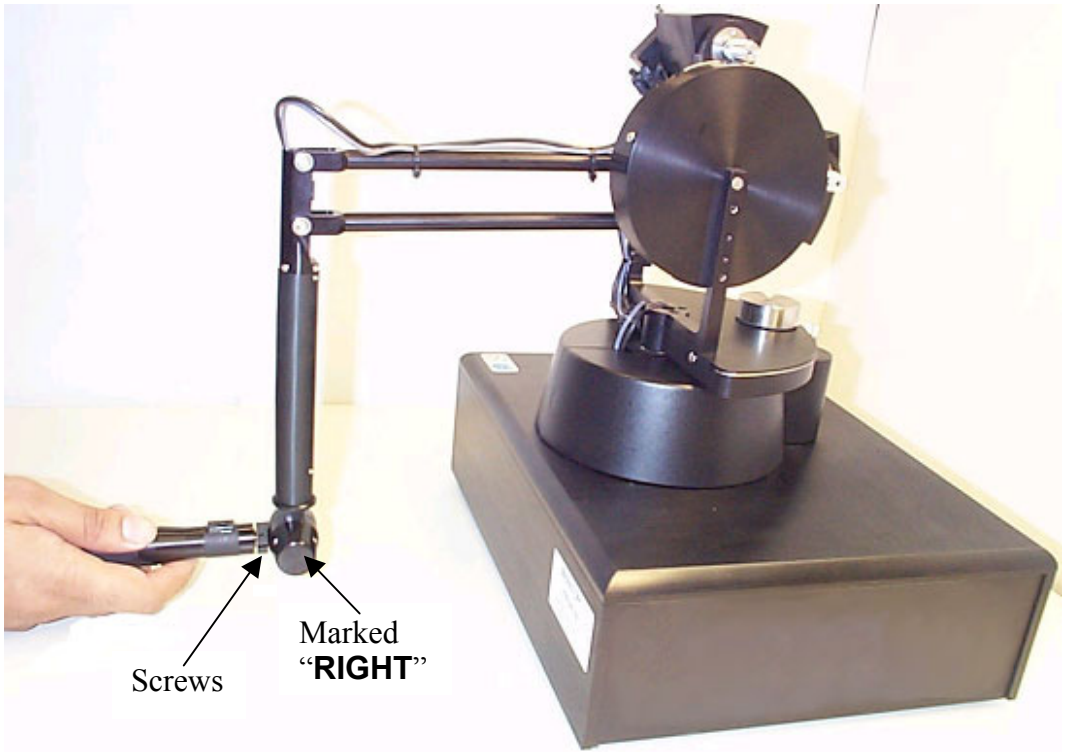


Figure 7: Correct initialization position (note that the screws are on the right hand side of the handle).

Power Assist (1.5/6DOF Only)

The PHANTOM ***PREMIUM 1.5/6DOF*** is equipped with power assist to improve the feel of the torque axes. Because of variability in the devices and in your individual software needs, you may find that these values need changing. Also, while debugging an application, you may prefer the power assist to be entirely shut off, so that you can focus on the torques that your own application is sending to the device without any added effects from power assist.

To change the behavior of the power assist, you can change several environment variables which affect power assist.

Variable	Value	Effect
STI_USE_POWER_ASSIST	1	If this variable is set to 1, power assist on the torque axes. If it is not set, power assist is turned off. By default there is no power assist.
CFRICTION_CUTOFF_AXIS4	0.1-1.0	This value is used for the yaw axis (handle left-right) to vary its power assist level. If it is not set, the initial value used will be 0.4. Adjust value if it feels like you need more or less power assist.
CFRICTION_CUTOFF_AXIS5	0.001-0.01	This value is used for the pitch axis (handle up-down) to vary its power assist level. If it is not set, the initialvalue used will be 0.001. Adjust value if it feels like you need more or less power assist.
CFRICTION_CUTOFF_AXIS6	0.1 – 1.0	This value is used for the roll axis (handle twist) to vary its power assist level. If it is not set, the value used will be 0.8. Adjust the value accordingly. If the handle is moving back and forth on its own before you adjust power assist, try a new value of 0.2 or 0.1.

Under Windows NT, to change an environment variable, go to the Control Panel and choose System. Under the "Environment" tab, you'll see a list of environment variables. To type in a new one, type it in the "Variable" box, and then type the value in the "value" box, and then click "set." To delete the variable entirely, find it in the list of environment variables, select it, and hit delete.

Under Windows 2000/XP, to change an environment variable, go to the Control Panel and choose System. Select the "Advanced" tab and click on the "Environment Variables" button. To type in a new one click on the "New…" button and then fill in the

variable name and the value in the dialog box that comes up. To delete the variable entirely select it in the list and click “Delete”.

Appendix A – Installing/Removing the Encoder Gimbal

Removing the Encoder Gimbal and counterweights from a PHANTOM *PREMIUM*

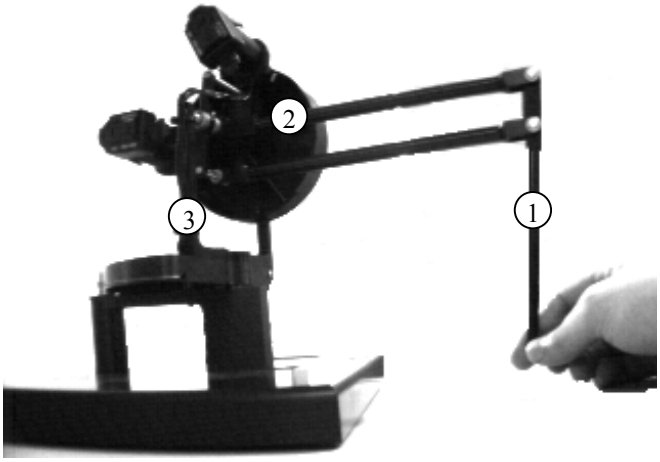
1. Unplug both the power and parallel cable from the PHANTOM.
2. Unplug the 26 pin connector on the PHANTOM ***PREMIUM*** base.
3. Cut the cable ties that route the cable with the 26 pin connector. Be careful not to cut any part of the cable. Note the routing of the cable as you take it off.
4. Using the Hex key provided (0.050") (SensAble part number 01641), loosen the #4-40 set-screw (SensAble part number 01509) located near the end of the last link.
5. Pull the encoder gimbal assembly out of the last link. The gimbal should slide out with a minimal amount force.
6. Hold both counterweight pieces in one hand to avoid dropping them. Using a 9/64" hex key (SensAble part number 01629), remove the two screws in the counterweights and remove the counterweights.
7. Insert the bare shaft of the thimble-gimbal into the end of the last link. Be sure that the shaft is inserted as far into the last link as possible, to preload the bearings and prevent any play in the device.
8. Lightly tighten the set-screw. Be careful not to tighten it too much: it could strip the threads and/or mar the shaft.
9. Plug in the power and parallel cables.

Adding the Encoder Gimbal and counterweights to a PHANTOM *PREMIUM*

1. Unplug the power and parallel cables.
2. Loosen the #4-40 set-screw in the last link using the hex key provided (.050") (SensAble part number 01641).
3. Remove the thimble-gimbal from the last link by pulling it out with a slight force.
4. Insert the bare shaft of the encoder gimbal assembly into the end of the last link of the PHANTOM ***PREMIUM***.
5. Lightly tighten the set-screw. Be careful not to tighten it too much; it could strip the threads and/or mar the shaft.

6. Plug the 26-pin connector into the socket located on top of the PHANTOM ***PREMIUM***.

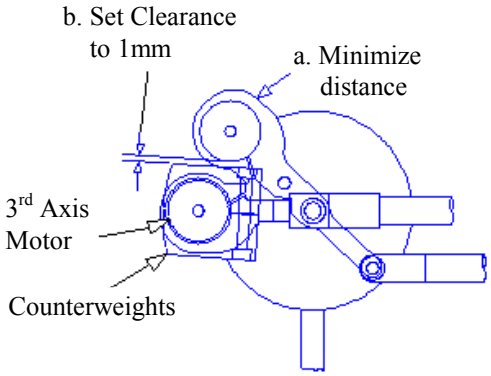
7. Using the small cable ties included, fasten the cable to the mechanical arm so that the cable will not interfere with the movement of the PHANTOM ***PREMIUM*** in any way. Be sure to leave enough slack near the encoder gimbal so that it can rotate 360°. A dressed PHANTOM ***PREMIUM*** 1.5A should only have three ties: #1 on the gimbal arm, #2 on the upper bar, and #3 on the front of the left support facing towards the back of the unit.



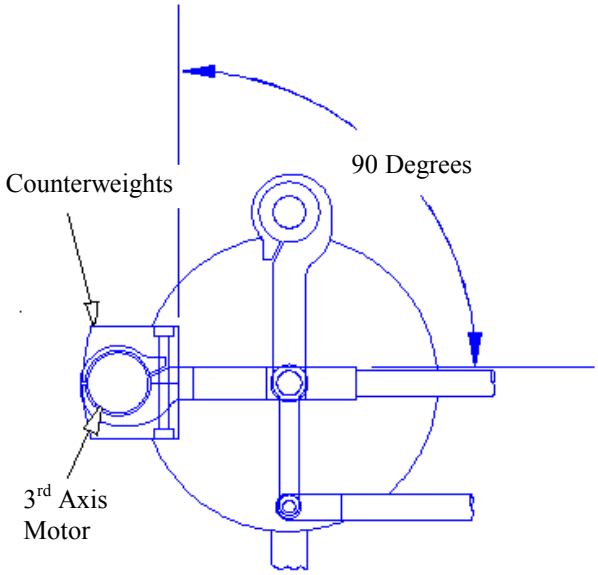
8. Cut the excess material from the ends of the cable ties.

9. Plug in the power and parallel cables.

For a PHANTOM *PREMIUM* 1.0A: Position the counterweights on the on the 3rd axis motor as shown at right, being careful to avoid the motor driver wires. The counterweights should be approximately 1mm (.040") away from the motor mount *in the motor axis direction*. You may have to bend the motor driver terminals to 60° away from the motor to make room for the counterweights; do this carefully. With a 9/64" hex key (provided), insert and tighten two 8-32 screws just enough to hold the counterweights in place. Now hold the two motors together, loading them against the mechanical stops and minimizing the distance between them (a). Rotate the counterweights until there is approximately 1mm (.040") clearance as shown (b) and tighten the 8-32 screws to secure them.



For a PHANTOM *PREMIUM* 1.5A:
Position the counterweights on the 3rd axis motor as shown at right, being careful to avoid the motor driver wires. The counterweights should be perpendicular to the PHANTOM ***PREMIUM***'s arms. The counterweights should be approximately 1mm away from the motor mount in the motor axis direction. You may have to bend the motor driver terminals to 60° away from the motor to make room for the counterweights; do this carefully. Insert and tighten two 8-32 screws to secure them.



SAFETY NOTES

The label attached to the base of the PHANTOM ***PREMIUM***, and shown below, indicates the user to exercise care in use of the device as follows;

- DO NOT put your face in the workspace of the PHANTOM ***PREMIUM*** 1.0A/1.5A. Safety glasses are recommended.
- DO NOT place your fingers inside the mechanism. At the installation site, access to motors and pulleys should be prevented.

Appendix B: Customer Support

NOTE: DO NOT OPEN THE UNIT. There are no serviceable components in the PHANTOM ***PREMIUM*** or power supply. Return to SensAble for servicing.

If you encounter any difficulties, you can obtain Technical Support through the following three channels:

- If you purchased your PHANTOM ***PREMIUM*** from a distributor, please contact them first.
- SensAble Technologies Customer Support can be reached via e-mail at support@SensAble.com.
- SensAble Technologies Customer Support can also be reached via telephone:
  - In the United States: 1-888-SENSABLE (1-888-736-7225).
  - Outside the United States: +1-781-939-7444

Appendix C: Caring for Your PHANTOM

The PHANTOM ***PREMIUM*** is one of a kind. It is important that the device be used with care in environments for which it is designed.

Some do's, do not's, and cheap tricks:

- DO start the device at the neutral position without fail.
- DO grip the handle firmly in an application that applies torques (**1.5/6DOF**).
- DO use small hand motions near the neutral position.

- DON'T drop the device!
- DON'T apply sharp impact forces to any part of the device!
- DON'T ram any movable member into a hard stop with great force!
- DON'T let go of the device in the middle of an application!
- DON'T twist the handle past its physical limitations.

- Try to minimize unnecessary vibration to the device.
- Turn off the switches in the back to debug without forces and torques. (**1.5/6DOF**).

Appendix D: Troubleshooting

If your PHANTOM ***PREMIUM*** does not operate as expected, call SensAble Technologies immediately for further assistance. Do *not* proceed further until you call our toll-free number (1-888-SENSABL) and ask for Customer Support, or email SensAble at support@sensable.com.

When contacting Support, you may be asked to run the "PHANTOM Test" application to help with diagnosis. This application can be found in the directory where you installed the PHANTOM Device Drivers.

The following describe the basic features of this test application which you should be prepared to run.

Select – Select the PHANTOM device which you want to test. Usually this will be "Default PHANTOM".

Read Encoders – The values being sensed for the positions and rotations of the device are dynamically displayed in the window. It additionally will display whether the stylus switch is pressed or not and whether you are holding the device (presence switch=on). The picture of the PHANTOM ***PREMIUM*** should change dynamically as you move the stylus around.

Cycle Amps – This will simply turn the amplifiers off then on again repeatedly to test their functioning. You should hear the device clicking on and off.

Test Forces – **IMPORTANT**: ***Hold onto the stylus when executing this test.*** Move the sliders with your mouse to generate forces which push against your hand. X controls force parallel to the table. Y controls force up and down. And Z controls force in and out.

Box Test -- Provides a box which you can feel with your PHANTOM ***PREMIUM*** **.** The sides of the box should feel flat and the corners sharp.

Quit – Quits the test application.

Appendix D-1: Configuring Multiple Devices

Multiple Devices

If you want to use more than one PHANTOM device with your computer, you can create as many as 20 uniquely named PHANTOM configurations. Each named PHANTOM configuration can refer to a particular system configuration that you use frequently. Which device to use is defined by the software application which uses it. All demonstrations installed with the PHANTOM Device Drivers use "Default PHANToM" as the configuration.

To create a new PHANTOM configuration, simply select the **Add** button and key in a name to call that device. Then, follow the instructions previously given for defining the configuration for that device. See the GHOST Programmer's Guide for more information on using this configuration within an application.

Dual Configurations

The Dual Configuration settings only apply if you want to set up a pair of PHANTOM devices to work in tandem with each other. You must have created at least two PHANTOM devices as described above before the Dual Configuration tab becomes useful. Once you have created at least two devices, go to the Dual Configuration area and select the PHANTOM devices you would like to use in a paired configuration. Then, enable the check box to turn the dual configuration on.

(Note: The Dual PHANTOM demonstration program that is shipped with the PHANTOM Device Drivers requires that the devices be named "PHANToM 1" and "PHANToM 2".)

Appendix E: PHANTOM *PREMIUM* Specifications

PHANTOM *PREMIUM 1.5/6DOF*

Nominal resolution	*Translational*		0.001	inch	0.03	mm
	Rotational, yaw&pitch		0.0023	degrees	0.00004	radians
	Rotational, roll		0.0080	degrees	0.00014	radians
Workspace	*Translational*		7.5x10.5x15	inch	19.5 x 27 x 37.5	cm
	Rotational, yaw&roll	appx	335	degrees	5.847	radians
	Rotational, pitch	appx	260	degrees	4.538	radians
Friction (average values)	*Translational*		0.15	oz	0.04	N
	Rotational, shin	less than	3.5	oz-in	14.11	mNm
	Rotational, middle	less than	2.5	oz-in	10.58	mNm
	Rotational, handle axis	less than	1.0	oz-in	7.05	mNm
Maximum exertable force and torque	*Translational*		1.9	lbf	8.5	N
	Rotational, top 2 axes		73	oz-in	515	mNm
	Rotational, handle axis		24	oz-in	170	mNm
Continuous exertable force and torque	*Translational*		0.3	lbf	1.4	N
	Rotational, top 2 axes		27	oz-in	188	mNm
	Rotational, handle axis		7	oz-in	48	mNm
Worst case stiffness (approximate values)	*Translational*		20	lbf/in	3.5	N/mm
	Rotational, top 2 axes	greater than	14.55	oz-in/deg	5873	mNm/rad
	Rotational, handle axis	greater than	14.55	oz-in/deg	5873	mNm/rad
Average stiffness (approximate values)	*Translational*		20	lbf/in	3.5	N/mm
	Rotational, top 2 axes	greater than	14.55	oz-in/deg	5873	mNm/rad
	Rotational, handle axis	greater than	14.55	oz-in/deg	5873	mNm/rad
Inertia (apparent mass at tip)*	*Translational*	smaller than	0.2	lbm	90	g
	Rotational, shin	smaller than	0.24	lbm	108	g
	Rotational, middle	smaller than	0.18	lbm	80	g
	Rotational, handle axis	smaller than	0.09	lbm	40	g
Footprint			10x13	inch	25 x 33	cm
Height			14	inch	36	cm
Weight			20	lbs	9	Kg
Backlash, no load	*Translational*		N/A		N/A	
	Rotational, top 2 axes		0	degrees	0	radians
	Rotational, handle axis	less than	4	degrees	0.070	radians
Mechanical bandwidth	*Translational*					
	Rotational	roughly	15.000	Hz		
Degrees of freedom	*Force feedback*		6 degrees of freedom			
	Position sensing		6 degrees of freedom			
Weight of the device	*Appx.*		21	lbs	9	Kgs

	PHANTOM *PREMIUM* 1.0A		**PHANTOM *PREMIUM* 1.5A**	
Nominal Position Resolution	860 dpi	0.03 mm	860 dpi	0.03 mm
Workspace	5x7x10 in	13x18x25 cm	7.5x10.5x15 in	19.5x27x37.5 cm
Backdrive Friction	0.15 oz	0.04 N	0.15 oz	0.04 N
Maximum Exertable Force	1.9 lbf	8.5 N	1.9 lbf	8.5 N
Footprint	10x13 in	25x33 cm	10x13 in	25x33 cm
Weight of the device	19 lbs appx		20 lbs appx	

**Does not include cables.*

Appendix F: Power requirements

	With Internal Auto-Switching Power Supply.
Output Current Rating	8.3 A
AC Input	100 ~120 VAC. 200 ~ 240 VAC (auto-switching power supply)
Input Frequency	50/60 Hz
AC Current	5A / 115V, 2.5A / 230 V
Inrush Current	15A / 115V, 30A/ 230 V

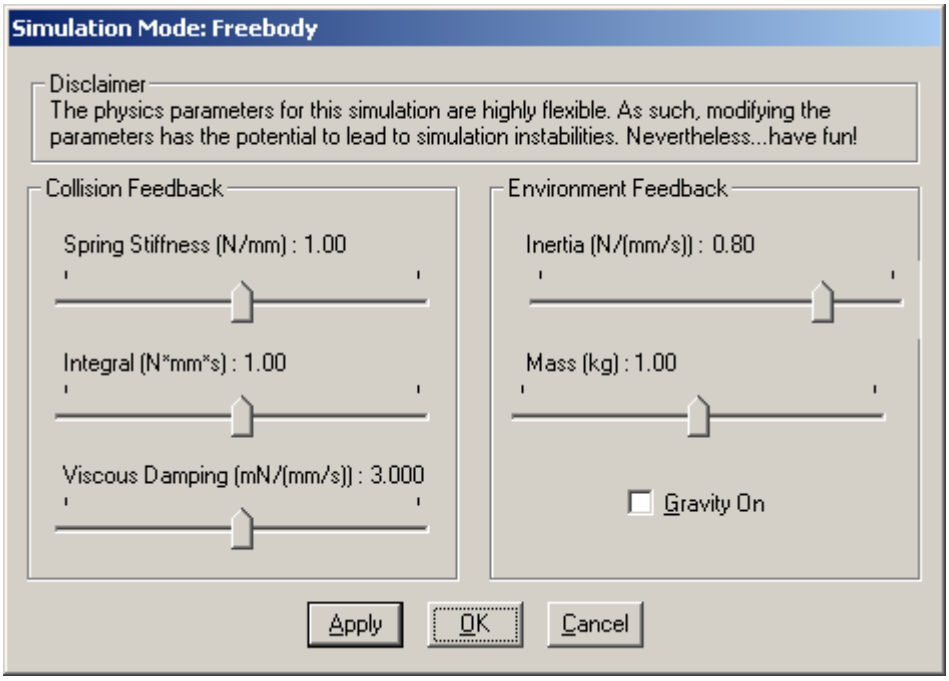
Appendix G: Dice Demo Notes

The primary purpose of the dice demo is to give an example of rigid body simulation using the GHOST SDK. The rigid body in this case is a cube that's confined to a box environment. The cube has several physical properties that control how it responds to collisions with the PHANTOM's surface contact point as well as the bounding environment.

You can interact with the cube in two fundamental modes. The first mode involves poking at it with your 3D cursor. Every time you make contact with the cube, you impart some force on a face of the cube. This can result in both linear and rotational motion. The second mode of operation allows you to grab hold of the cube and directly control its position and orientation. While in this mode, you can feel the bounding environment via the cube's collision interactions. To activate this mode, simply hold the stylus button while making contact with the cube. The cube will then attach itself to the PHANTOM's endpoint.

While you're playing with this demo, you can also experiment with modifying some of the dynamic physical properties. As a first note of caution, changing the simulation parameters may lead to numerical or mechanical instabilities, so don't be surprised if the cube's behavior becomes erratic.

The dialog box displayed below depicts the physics parameters that can be modified by the user at runtime. The first set of parameters is grouped under the heading "Collision Feedback" and is used for controlling the cube's response when colliding with and penetrating the bounding environment. These settings are used within a proportional, integral, and differential controls model for responding to environment collisions with the cube's 8 corner vertices. The other properties grouped under the heading, "Environment Feedback" are used for the rigid body simulation in determining the kinematics behavior.



The aforementioned "Collision Feedback" parameters are set specifically for the two different modes: freebody and grab mode. When the cube is behaving as a freebody, the parameters tend to be set high, which offers the advantage of having stiff interactions with the bounding environment. However, when grab mode is enabled, the parameters need to be set lower to avoid mechanical instabilities with the PHANTOM that result from high stiffness interaction. You can interactively change these settings while the dialog box is active and then hit the "Apply" button to immediately experience the results.

Here's a quick guide on how to interpret these parameters and to have some intuition for your own development efforts. In general, you want to specify control coefficients such that they lead to a critically damped system (i.e. errors tend towards zero over time).

The proportional control coefficient (sometimes referred to as stiffness) is typically the most important factor in a haptics application. The coefficient dictates the relative force to be applied in response to a surface penetration. In physics speak, this is basically hook's law, which governs the behavior of springs. When using Ghost, you can typically get the maximum proportional gain for your PHANTOM by calling gstPHANToM::getMaxGain() on your PHANTOM instance. Using a proportional gain higher than this value will result in frequent buzzing or max force errors.

The second most important controls parameter is the differential control, which provides velocity damping. By definition, differential control is proportional to the change in position over time. It will generally try to dampen velocity in the system and is useful in promoting critically damped behavior.

The third less commonly used parameter is integral control. This works great for eliminating any residual error in the system but takes time to work effectively. This form of control is a

summation of penetration depth over time, thus you will often feel the die gradually ramp up its force until the penetration depth goes to zero.

When applying these terms to different PHANTOMs, you'll find that each PHANTOM responds a little differently. Settings that work well for a PHANTOM Model A 1.0 will not necessarily work well with a PHANTOM 1.5/6DOF. Since this demo can make use of 6 degrees of force feedback (i.e. forces and torques), you have to be even more conservative when dealing with a 6DOF device in a generalized force model. When a 6DOF is used with the program, the stiffness and damping are automatically set lower than normal. This results is a more mechanically stable model, but the tradeoff is rigidity in the cube's grab mode interactions.

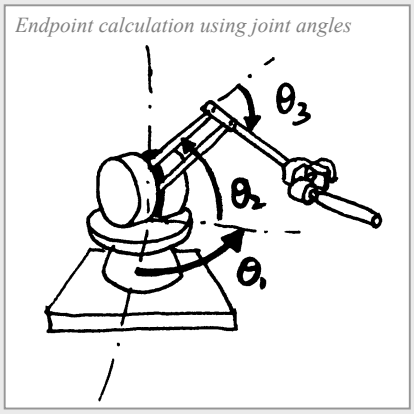
Note: There are some known limitations to the numerical and mechanical stability of this demo program. You may find that the extents of the workspace exhibit buzzing in the PHANTOM arm or that the cube doesn't always reach a stable resting state when forced into corners. These are partially due to the appropriateness of the control parameters for the particular collision type. This demo could also benefit from using a rotational spring-damper model for controlling torques.

Appendix H - Maximizing Positioning Accuracy

The objective of this technical note is to help you achieve a high level of positioning accuracy in the PHANTOM devices as specified in our product literature.

PHANTOM devices have excellent inherent *repeatability* under no-load conditions. However, they can only be *accurate* if they have been initialized properly. The proper procedure for initialization is outlined in this note.

Why initialization matters



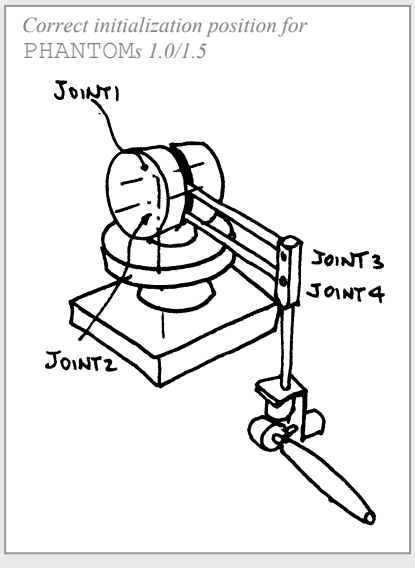
Endpoint calculation using joint angles

All PHANTOM devices are equipped with incremental rotary encoders, which measure the joint angles of the PHANTOM mechanism. These measurements are then used to calculate the endpoint position in Cartesian space, based on the linkage structure, link lengths and other such parameters.

This method of arriving at the endpoint position implies an absolute knowledge of the joint angles. However, incremental encoders can only provide angular measurements relative to the joint angles at which the system "woke up" at initialization time.

To obtain absolute angular measurements, the system must initialize at a known position and orientation. Any deviation from this

Initialization position for Phantom Devices



Correct initialization position for PHANTOMs 1.0/1.5

To keep the initialization procedure simple, we have chosen an easily recognized point in the center of the workspace of the PHANTOM. Roughly speaking, the correct startup position involves keeping the first link horizontal and perpendicular to the front face of the base, and the second link vertical and pointing down from the first. If there is an encoder gimbal, the face of the gimbal with a label indicating "This side faces the PHANTOM" should be vertical and it should face the base of the PHANTOM. The thimble or stylus should be horizontal in the plane of the first and second linkages.

The goal of this procedure is to line up the four rotary joints of the PHANTOM 4-bar linkage to form a rectangle. If the two joints on the short linkage closest to the base are called Joints 1 and 2, and the joints on the second linkage are called Joints 3 and 4, the lines between Joints 1 and 3 and Joints 2 and 4 must be horizontal, and the lines between Joints 1 and 2 and Joints 3 and 4 must be vertical.

To eyeball or not to eyeball

Given that the initialization position dictates future positioning accuracy of the PHANTOM, is it sufficient to eyeball the startup position or is it necessary to create a fixture to ensure accurate and repeatable system initialization?

The answer to that question depends greatly on the application. The figure, below, shows typical positioning errors for a PHANTOM 1.5 when the initialization position is translated by a typical "eyeballing" error of 0.2" in the –x and –z directions. The best-case error is around the initialization point with the errors growing larger near the edges of the workspace. Furthermore, there is some skewing of the coordinate system. Due to the error in reported position, the forces presented to the user will also be similarly skewed.
However, the human is an imprecise position and force measurement device and such differences are generally not perceivable. For applications in which a single PHANTOM is used to present forces in a virtual reality simulation, eyeballing is generally adequate. On the other hand, for applications in which position is critical, such as teleoperation, 3D digitization or operation of two PHANTOM s in the same virtual space, it is generally advisable to create a jig for accurate initialization.

Getting help

We hope that this note helps clarify the issues around the initialization procedure. If you have any further questions please do not hesitate to contact us.