HiBall-3000/3100 Wide-Area Tracker

User Manual

Software Revision 1.8

Manual Revision A

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1 Introduction

The HiBall-3000/3100 Wide Area Tracker is an optical, high-performance tracking system based on technology first developed by the Wide Area Tracker research group of the Computer Science Department at the University of North Carolina at Chapel Hill. The system provides a unique approach to high-performance tracking.

- The HiBall Tracker uses an *inside-looking-out* format with sensors on the user (the object being tracked) and landmarks (Beacon Arrays) on the ceiling. This enables the system to scale to very large areas – upwards of 1600 square feet (148 square meters). It also provides unprecedented resolution and accuracy for position and orientation.
- A major design goal of the HiBall Tracker was low latency to prevent the 'swimming' associated with the lag between head motion and tracker update rate of most commercial trackers.
- An optical tracker is unaffected by metallic or acoustic interference. Furthermore, the accuracy and performance are uniform throughout the tracking area.

This manual describes the design and operation of the HiBall-3X00 tracker system. Additional information about the development of the HiBall Tracker and associated research is available on the UNC web site at

http://www.cs.unc.edu/~tracker/

A PDF version of this manual is also on the system software CD in the *doc* directory. You can download the latest version of Adobe Acrobat (a free PDF file reader) from *http://www.adobe.com*.

1.1 Overview of components

The HiBall-3X00 Tracker System is a complete tracking solution. Figure 1 shows its hardware components. These are:

1. The HiBall Sensors – lenses and photodiodes in a lightweight casing which view infrared LEDs in the Beacon Arrays
2. Beacon Arrays – strips of infrared LEDs mounted on the ceiling or some surface overhead (alternatively they can be mounted on a wall)
3. CIB – Interface unit connecting the HiBall Sensors and Beacon Arrays with the PC controller (Note: Image is of the CIB-3000. The CIB-3100 is somewhat different.)
4. PC – Dedicated PC provides the interface between the CIB and client applications via an Ethernet connection.

Figure 1 HiBall-3000 Wide Area Tracker System

2 Installation

The HiBall-3X00 System was designed to be user installable and, in many common environments, requires no special modifications of the ceiling or tracking area.

2.1 List of components

A typical system includes the following components.

- Multiple Beacon Arrays (ceiling strips), power distribution boxes (PDBs), and cables.
- One CIB (Ceiling Interface Board) in box with power cord and EPP cable (IEEE 1284C), and ‘buttons’ parallel cable.
- One HiBall Server PC (Windows NT, 2000, or XP), with case, monitor, mouse and keyboard.
- 1 to 4 HiBall Sensors and matching tether cables (The HiBall-3100 can have up to 4 sensors.)
- HiBall software CD.
- A video camera for viewing LEDs

In addition, a monitor/TV for viewing LEDs with the camera provided is useful for installation and troubleshooting. This is described further in Section 2.2.4.

2.2 Step 1 – Initial configuration and system test

This section describes procedures for initial HiBall Tracker system installation, configuration, and system testing.

2.2.1 System Location

First, select the region you wish to track and the corresponding ceiling area – typically a little larger than the tracked region. (The range of angular tilt of the HiBall Sensor is somewhat limited near the edge of the Beacon Arrays. For a full angular range of motion we recommend extending the Beacon Arrays 2 ft. beyond the region to be tracked.)

Note: You will need an appropriate ceiling structure on which to mount the Beacon Arrays. They are designed to be installed in two different ways. They can be attached, with no additional hardware, to the support lattice of a typical 'drop' ceiling. (The ends of the two-foot long individual strips slide between the ceiling tile and support lattice – see Figure 2.) Alternatively, each strip has mounting holes (visible in the figure near the ends of the strips) by which they can be attached to a solid surface.

Figure 2 Beacon Arrays

The CIB Box (Figure 3) connects to the parallel ports of the HiBall System PC. A cable from the CIB box connects to a Power Distribution Box (PDB) located next to the first Beacon array strip in the daisy chain of strips. Generally, you will locate the CIB and PC near the corner of your ceiling area where the first strip is located. If your system has more than 128 Beacon Array strips (covers more than 170 square feet) these will be divided up into 2 or more 'banks' of strips. The first strip of each bank is cabled to the CIB and this will affect the placement of the CIB and PC.

Figure 3 CIB

To begin installation and testing of the HiBall system, connect a single strip to the CIB (it need not be in the ceiling.) The remainder of the strips will be installed later.

2.2.2 Connections and Power Up

The next step is to set up the HiBall PC **ALONE**.

> Note: Do NOT connect any other components to the PC. Do not connect the PC to your network yet.

Connect the standard monitor, keyboard and mouse to the HiBall PC and power it on. The PC has been pre-configured for the HiBall Tracker System. **Do not do any of the configuration steps described in the PC's documentation**. After the system boots you should see the standard Windows login prompt. Two user accounts have been set up:

- Login: `tracker`, Password: `tracker` – for running the HiBall tracker server or changing the tracker configuration.
- Login: `Administrator`, Password: `Administrator` – for changing the PC's configuration.

> Note: Capitalization is significant for login and password.

> **Note: These passwords are not particularly secure; you will probably want to change them according to your local security policy.**

> Note: Some PCs do not allow an account to be named "Administrator". On these PCs, only the "tracker" account is set up, but it has Administrator privileges.

Log on to the HiBall PC as 'tracker'. You should see several shortcuts on the desktop including 'HiBall Server', 'One Strip LED Test', 'hiball\bin prompt', and 'HiBall Files'. All HiBall Tracker files are typically installed under 'C:\hiball\'. (If you don't have the shortcuts you can run the programs directly from C:\hiball\bin\.) The file 'HiBall Installation Information' contains site-specific installation details that you will need to refer to later. Double-click its desktop icon to read this information when needed.

2.2.3 Connecting the CIB, HiBall Sensor, and a beacon strip.

Make the following connections with the CIB powered off.

> **WARNING: Always power off the CIB before connecting or disconnecting any cables.**

A note about grounding:

> **The HiBall uses extremely high-gain amplifiers and is therefore grounded to shield it from noise. This may make the electronics susceptible to static electricity in some high-static environments. Users need to be properly grounded before handling the HiBall or CIB.**

Connections:

1. Connect the standard EPP 1284 cable from the CIB connector labeled 'EPP Interface' to the parallel port on the PC which has been labeled 'CIB I/O'.

2. Connect the cable marked 'buttons' from the CIB connector labeled 'Stylus' to the parallel port on the PC labeled 'Buttons I/O'.

3. Connect a HiBall sensor to the CIB using a HiBall tether cable. Connect only one HiBall sensor for this system test. The *HiBall Installation Information* document indicates a default assignment of sensors to tether ports. Connect the HiBall assigned to 0. HiBall serial numbers are marked on the base of the HiBall.

   WARNING: HIBALL SENSORS ARE HIGHLY SENSITIVE, CALIBRATED INSTRUMENTS – HANDLE THEM CAREFULLY. DO NOT DROP.

4. Connect one Beacon Array strip to the CIB at the 'CEILING Banks', '0' connection using a CIB-to-strip cable. (Note: When the full system is installed, this cable will connect to a Power Distribution Box instead of connecting to the first Beacon strip. This is described later in the installation.) CIB-to-strip cables differ from strip-to-strip cables in length and in wiring. They are not interchangeable. The CIB-to-strip cables are 20 feet long (custom lengths are available). Both ends of the CIB-to-strip are the same. Connect either end to the 'In' end of a beacon strip, which is marked with a colored dot.

   NOTE: If the strip is on the ceiling, create a support for the cable near the connection to the beacon strip. Supporting the entire weight of the cable with the connector alone can damage the connector over time.

5. Connect the other end of the CIB-to-strip cable to the CIB at Ceiling Banks number 0.

   Warning: the beacon strips are not symmetric. Connecting strips backwards may damage them. The 'In' end of a strip is marked with a dot of yellow or red paint near the connector. A label on the back of the strip also indicates the 'In' and 'Out' ends.

6. Connect the power cable to the CIB and plug it in.

7. Connect the video camera (supplied) to a TV monitor and point the camera at the strip.

8. Power on the CIB.

2.2.4 Initial System Test

Run the 'One Strip LED Test' shortcut on the PC's desktop. This runs the command 'C:\HiBall\bin\ledtest.exe C:\HiBall\config\trackerOnestrip.cfg'. (To view or change a shortcut's command line arguments, right-click on it, select Properties and then click the Shortcut tab.)

This program will test communication between the HiBall PC, the CIB, the HiBall sensor, and the Beacon Array. It will open a DOS window and display several start-up status messages followed by a short menu. If you see error messages and no menu, quit the program (press CTRL-C or click on the ☒), check that all cable connections are as described in the previous section, and try again. The menu should appear as follows:

```
HiBall 3000 LED Test
Select one: n - fire next LED in row-column order
            p - fire previous LED in row-column order
            r - fire LEDs randomly
            s – scan full ceiling in row-column order
q – quit
```

If you see error messages, refer to Section 5 of this manual, which contains troubleshooting information that may help you determine the problem.

If there are no error messages and you see the menu, select 'n' to blink the first LED on the strip. It should print a message like

```
40 LED blinks in 0.078 s, 510 per second (0 bad)
```

This program fires the same LED 40 times so that it's easier for the user to see. If the message says there are bad reports, this may mean the HiBall is not connected properly.

> Note: The system is taking HiBall readings during this test, but you do not need to point the HiBall at the LEDs.

The LED blinks should be visible with the camera provided for installing your system, or with any camera that picks up Infrared (IR) signals. If the room is very bright, the camera may close its shutter and not pick up the LED flashes. Try turning off lights if this happens.

If you continue pressing 'n', the program will light up all the LEDs in sequence. The program has other options for other LED orders – 'r' for random, 's' for all LEDS in sequence. Verify that all 8 LEDs on the strip blink one at a time, and in order using the 'n' command, before you continue to the next step.

2.3 Step 2 – Configure Beacon Strips

Once you have run a successful initial system test you are ready to install and connect the remaining Beacon Array strips. We recommend reading through this entire section before beginning the ceiling installation.

> **Remember to power off the CIB before connecting or disconnecting any components!**

The system components you received should include the number of strips, PDBs, and cables required to build the ceiling configuration you specified. The software is also pre-set for this configuration. Check the *HiBall Installation Information* document for details on your configuration. If you need to change the ceiling layout, refer to Section 6.1 or contact 3rdTech. **We recommend that you connect and test the pre-configured Beacon Array first before you make any customizations.**

> Note: If you change the ceiling configuration you must also change the software configuration files. Refer to Section 6.1.

As an example, a standard Model C18 configuration (12 ft. x 12 ft., 108 Beacon Arrays) is shown in Figure 4 (layout diagram). Refer to the diagram included with your *HiBall Installation Information* document for the layout that corresponds to your configuration.

2.3.1 Beacon Strip Installation

The document *HiBall Installation Information* contains a list of the number of beacon strips, the number of cables and their lengths, and the number of PDBs in your configuration. A beacon strip is a single 2ft. x 1in. x 0.9in. strip with 8 infrared LEDs. (A Beacon Array Module (BAM) is a set of six Beacon Strips. For installation, we consider individual strips rather than BAMs.) A strip can be installed in a drop ceiling by sliding the ends between the tile and the support lattice, as shown in Figure 2, or by mounting on a solid surface using the two mounting holes. Cables come in several different lengths depending on where they are used in the ceiling layout.

There are both strip-to-strip cables and power distribution cables. Refer to your installation diagram to see which cables correspond to which connections.

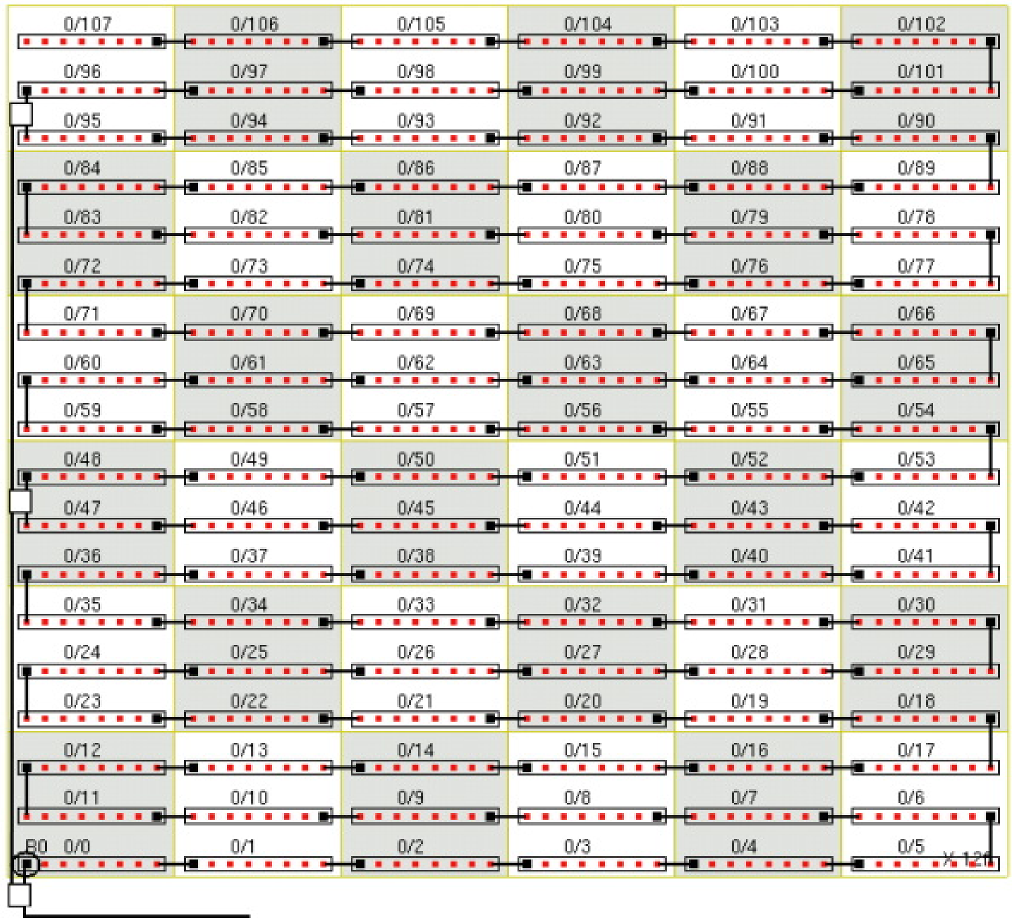

Figure 4 Ceiling Grid Layout – standard C18 (12ft. x 12ft.) as seen from above. The first LED on the first beacon strip is circled and marked with 'B0'. The X-axis extends from BO to the right. The Y-axis extends from BO to the top. A power distribution box is shown next to the first Beacon strip and others between rows 8 and 9, and rows 16 and 17.

Install the Beacon Strips

The beacon strips are typically connected end-to-end across the width of the ceiling and back again in a 'daisy chain' (other configurations are possible). Figure 4 illustrates the typical connection scheme. LED rows must be 8 inches apart (20.3 cm), i.e., three per 2ft. x 2ft. tile, 6 per 2ft. x 4ft. tile. Use the installation ruler provided to ensure you keep to the 8" spacing between rows (the ruler measures 7", which corresponds to the space from the inside edge of one strip to the inside edge of the next.) There is tolerance in the system for approximately ½ inch (1.3 cm) error in where you place the strips. The ceiling layout in the diagram illustrates a grid on 2 ft. by 2 ft. ceiling tiles (0.61 m by 0.61 m).

> Note: If your ceiling tiles are 2ft. x 4ft. the strips will be installed across the short dimension of the ceiling panel – 6 strips per panel.

Install the strips in your ceiling according to your custom diagram. The first strip in the ceiling is marked in the figure with ‘B0’ and with a circle around the first LED. This strip should be located near the CIB.

Strips are labeled in map diagrams as ‘bank#/strip#’ to aid in correctly connecting the strips. The ‘In’ end of a strip is marked in the diagram with a large black dot. It is very important to orient strips correctly – an ‘Out’ end must connect to an ‘In’ end. ‘In’ is marked with a colored dot (yellow or red) on the strip near the connector.

> **Warning: The Beacon strips are not symmetric. The ‘In’ end on a strip is marked with a yellow or red dot. Connecting strips backwards may damage them.**

Install the Power Distribution Boxes

Power Distribution Boxes (PDBs) distribute power over sections of a Beacon strip bank. Typical configurations will require a PDB for *approximately* every 30-60 Beacon strips. (Note: This will vary with the size, configuration and cabling of your configuration—see Section 6.1.2 for details.) Your map diagram shows the location of your PDBs. The PDB has a magnet and can simply attach to the support lattice of your drop ceiling as shown in Figure 5. If necessary, the cover of the PDB can be removed and the base of the PDB can be attached to the ceiling with screws, or it can be attached with the double-sided tape provided.

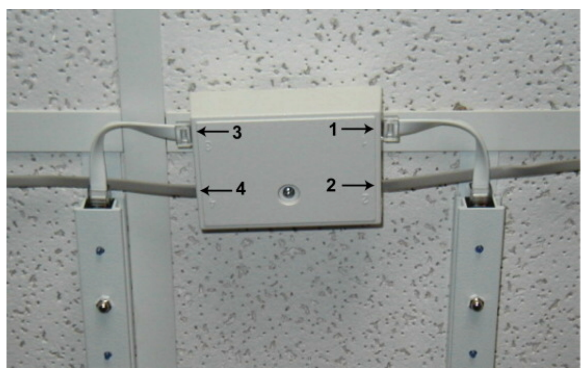

Figure 5 Power Distribution Box

Connect Cables

A CIB-to-strip cable connects the CIB to the first PDB for each bank of Beacon strips as shown in Figure 6. There are 4 numbered connectors on the PDB – two 8-conductor RJ45 (1 and 3) and two 6-conductor RJ25 (2 and 4). Connect the CIB-to-strip cable to connection 1 or 3. The other end of the cable connects to CIB bank 0.

> Note: It doesn’t matter which is selected – Figure 6 shows it connected to 1. However, if you select 1, then 1 and 2 are both ‘input’ connections and 3 and 4 are both ‘output’ connections. If you select 3, than the reverse is true. You may not mix inputs and outputs, e.g. you cannot make 1 an input and 2 an output.

> **Note: Remember to create a support for the weight of the CIB-to-strip cable.**

Now connect the *BO* strip to the other RJ45 connection (1 or 3; 3 in Figure 6) with a small strip-to-strip cable. If you have multiple banks, as marked in your layout diagram, then connect a

PDB to the corresponding bank port on the CIB, and to the first strip in each bank, in the same manner.

Figure 6 Power Distribution Box Connected to CIB and Strip 0

If you have more than approximately 36 Beacon strips in a bank you will have additional PDBs. These connect 'in line' as shown in Figure 5. Connect the 'out cable' from one strip to connection 1 or 3 and the 'in cable' from the next strip to the other RJ45 connector. In addition, a 6-conductor Power Distribution cable connects the first PDB (RJ25 connector 2 or 4; 4 in Figure 6) to the 'input' connector 2 or 4 of the next PDB in the same bank (as shown in Figure 5).

> Note: In Figure 5, if 1 is selected as an input, then 2 must be the other input and 3 and 4 are outputs. If 3 is selected as an input, the 4 must be the other input and 1 and 2 are outputs.

2.3.2 Full Ceiling Test

Once all the ceiling strips are installed, as well as a single HiBall Sensor (you must have a HiBall Sensor connected to do the next test), turn on the CIB power. Now run the *Full Ceiling LED test* shortcut (this runs the program *ledtest*, as in Section 2.2 with your main tracker configuration file – see your Installation document for the name of that file, and be sure the map it references matches the actual ceiling layout being tested). This test will verify that the strips are connected and functioning properly. You should use the video camera and TV to view the LEDs as they fire as you did in the earlier test.

The program should display the same options as described in Section 2.2. Use the 'n' command to step through all LEDs in the ceiling to verify that they work. This will light LEDs in 'row-column' order. The first LED that fires will be LED 0 on strip 0 – the first strip connected to the CIB (this LED is circled in the ceiling map diagram). The next LED is the next one along that strip. The next LED is the next on that strip, and so on in that row all the way across the ceiling. Then it will start back at the beginning of the next row, and so on.

> **Verify that all LEDs in the ceiling light in exactly the correct order (using the 'n' and 'p' commands).** Once you've verified this you can do subsequent tests, when necessary, using the faster 'r' (random) or 's' (scan all) tests, which quickly determine what LEDs are firing (though they will not verify the ordering).

Possible problems you may see are:

- LEDs not firing beyond a certain point in the ceiling
- Certain LEDs staying on all the time while other LEDs are firing.

If any problems occur, power down the CIB and check connections. Make sure that strips are not reversed.

Remember to turn off the CIB before connecting or disconnecting any components.

If problems continue, try testing the ceiling in increments – add one row at a time, or connect different subsets of strips (making sure that strips are not reversed) – to identify the location of the problem.

Note: For these tests you can have fewer strips connected than are in your ceiling map. Also, you need to have one HiBall connected for these tests – though you do not need to point it at the LEDs.

Try to isolate the strip or cable where the problem begins, and remove it. In these incremental tests, use the 'r' and 's' commands. Also check that the tracker configuration file that you are specifying when you run *ledtest* corresponds to the tracker configuration file named in your installation document. If the problems remain unresolved, or if you determine that any of the strips or cables are defective, contact 3rdTech.

If all LEDs on the ceiling fire correctly in this test, the system is ready to begin tracking as described in Section 3. If you have additional HiBall sensors you will connect them in the next section, otherwise skip to section 3.

2.4 Connecting additional HiBall sensors

To connect a second HiBall sensor, **turn off the CIB** and connect the sensor to the CIB tether port according to your installation document. The standard 'two-HiBall configuration' in that document specifies which HiBall sensor should connect to which HiBall port. (HiBall-3100 systems can have similar configurations up to 4 HiBall sensors.)

Note: Each HiBall sensor has its own configuration and calibration files (each sensor is calibrated individually to correct for slight differences in manufacturing). You must make sure that the HiBall physically connected to a given HiBall port matches the assignment in the *Tracker Configuration File.* See Section 6.2 for a description of the configuration files.

2.5 Mounting HiBall sensors

To mount a HiBall sensor on a head-mounted display, on the HiBall Stylus, or on other objects, use the two mounting holes in the base of the HiBall sensor. These take standard 6-32 screws. The two holes are 1.04 inch (26.46 mm) from center to center along the X axis. There is also a single hole in the center, size ¼-20 (standard camera mount thread). All three holes are 11/64" (4.5mm) deep. DO NOT ATTEMPT TO FORCE SCREWS ANY DEEPER THAN THIS – YOU COULD DAMAGE THE HIBALL SENSOR.

3 Operation

3.1 Running the HiBall Server

Once the system components have been connected and the Beacon Arrays have been tested, you are ready to power on the CIB and run the HiBall Server. This program starts the system tracking, generates measurements, and relays them (as VRPN reports) to client applications.

You can run the server directly from the desktop shortcuts that have been set up on the HiBall server PC. There should be a standard shortcut called *HiBall Server* that runs the default number of sensors (one or two, as described in your *HiBall Installation Information* document) as well as additional shortcuts for other combinations of sensors.

Alternatively, you can run the HiBall server directly from a DOS prompt, specifying the appropriate VRPN server configuration file. There's a shortcut on the desktop to get a DOS prompt in the C:\HiBall\bin folder. Run

vrpn_server –f C:\HiBall\config\vrpn.cfg

Running other applications on the PC can seriously degrade HiBall Tracker performance. Small applications like Notepad and virus protection software should cause no problems.

3.1.1 HiBall Server Control Panel

When you run the HiBall Server program it will output status messages to a DOS window and it will bring up a graphical control panel, shown in Figure 7. (If the control panel does not appear, check the DOS window for error messages, and double-check physical connections. If the DOS window disappears, try opening a new DOS window and running the server from the prompt, as described above. To check which configuration file argument the shortcut uses, right-click on it and select 'shortcut'.)

The top part of the control panel shows the following:

- *HiBall update rates* for all running HiBalls. HiBall 0 is the first HiBall referenced in the Tracker Configuration File (typically the one on HiBall port 0). HiBall 1 is the second HiBall referenced in this file, and so on. At startup, and when a HiBall is outside the range of the ceiling, this will show a red 'ACQ', indicating that the tracker is acquiring (see below for details).

  Note: A typical measurement rate for a single HiBall sensor is 1000 to 2000 Hz. For two sensors, the measurement rate for each decreases by approximately half. Measurement rate also varies somewhat with the sensor's location in the environment. The rate may decrease when the tracker is near the edge of the tracking region or near the floor. Small changes in measurement rate (within a few hundred Hz) have no noticeable effect on tracking performance.

- *Uptime* shows how long the HiBall server has been running.
- *Details* button hides or displays the lower part of the panel.

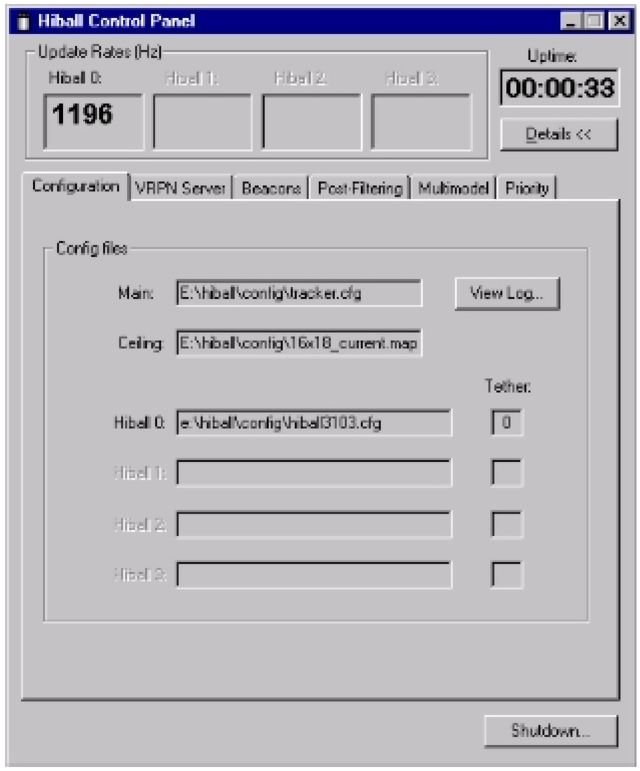

Figure 7 HiBall Server control panel.

At the bottom of the control panel is the *Shutdown* button to stop the tracker.

The central part of the control panel has six tabs. The *Configuration* tab lists the configuration files the tracker is using, and indicates which HiBall is connected to which port. Refer to your *HiBall Installation Information* document for more details about the files installed on your system. In addition, it has the *View log* button to view status information saved to a file in C:\HiBall\logs\. The server keeps the 10 most recent log files in that folder.

The *VRPN Server* tab contains the following information about VRPN and client-server communication properties (see Figure 8).

- *Connections* – shows whether a client application is connected from another machine, and the length of time it has been connected.
- *Report rate (Hz)* – shows the rate at which the server is relaying VRPN tracker reports to clients. This number can be set in the VRPN configuration file (see Section 6.2).
- *VRPN version* – shows the VRPN version that was compiled with the HiBall Server. The major version number (which is 6 in the figure) must match the major version number of the copy of VRPN that you use with your client code. See Section 6.4 for information about software upgrades.
- *HiBall system software version* – shows the version of your HiBall system. Refer to this version number when contacting 3rdTech for support or assistance.

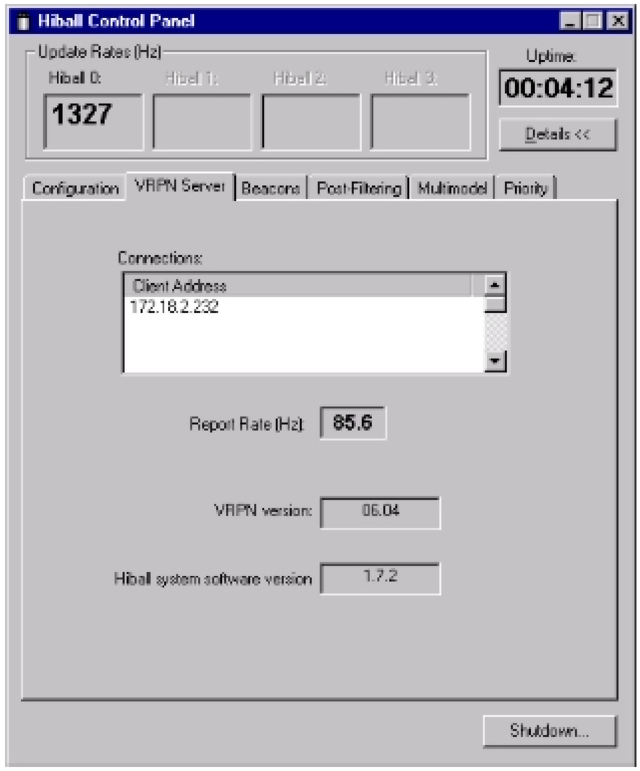

Figure 8 HiBall Server control panel, showing VRPN server details.

The *Beacons* tab indicates whether Beacon Autocalibration is on or off, and allows you to save calibrated ceiling maps. See Section 6.3 for more information on customizing autocalibration.

The *Post-Filtering* tab (see Figure 9) allows you to apply different types of smoothing filters to the tracker measurements in order to minimize jitter. You should use post-filtering only if jitter is noticeable in your application. Only one type of filter may be applied at a time.

- *No filtering* – if this box is checked, no post-filtering is applied.
- *Median*– applies a median filter to tracker measurements. The value that is sent through VRPN is the median of the last N measurements. This field accepts values of N between 3 and 23.
- *Averaging (ms)* – this applies a moving window averaging filter over the specified number of milliseconds to smooth the data. We recommend approximately 100 ms or less. Larger values will add noticeable latency.
- *Exponential averaging* – this applies an exponentially weighted moving window averaging filter. This is similar to the averaging post-filter but it places more weight on recent records and adds much less latency. Values can be between 0 and 100. Values between 80 and 97 effectively reduce large amounts of jitter without adding noticeable latency.

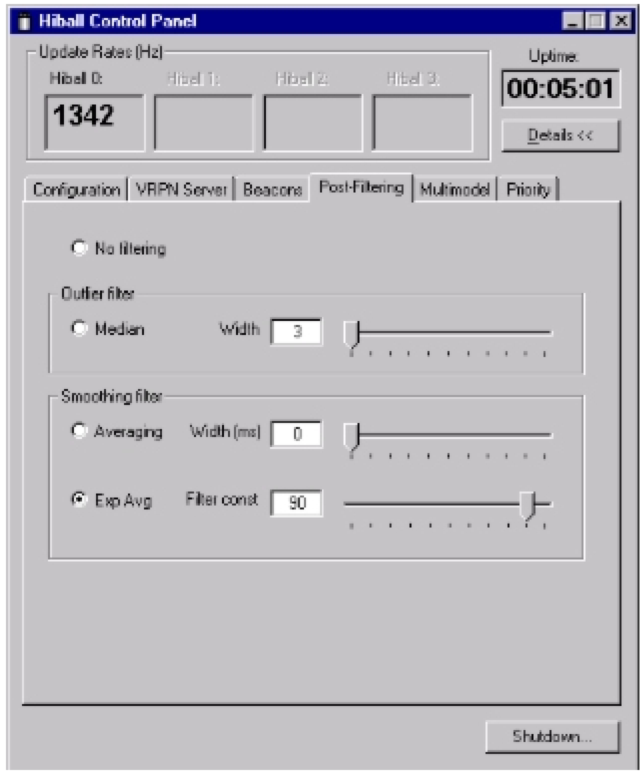

Figure 9. Post-filtering tab in the HiBall Control Panel.

The *Multimodel* tab contains information about the multimodel Kalman Filter switching. We recommend keeping multimodel switching enabled at all times (except while generating a new, autocalibrated ceiling map). This is the default in configurations shipped with HiBall Software Release 1.3 or later. See Section 6.4 for more information.

The *Priority* tab allows you to adjust the relative priority of each sensor when tracking with three or more HiBalls. When using one or two HiBalls, the priority scheduling software is turned off by default. This panel also allows you to temporarily disable one or more HiBall sensors without restarting the server.

3.1.2 HiBall Tracker operation

Acquisition and tracking

On startup the system will attempt to begin (or 'acquire') tracking for each HiBall sensor that is connected. If a sensor has not yet acquired tracking a red *ACQ* will appear in place of the measurement rate. Acquisition normally takes 1 or 2 seconds.

> Note: The system executes Acquisition to find an estimate of the sensor's location given no initial information.

Once acquisition succeeds, the tracker proceeds by rapidly updating its estimates after each LED blink using the SCAAT (Single-Constraint-AT-A-Time) Kalman Filter. Tracking updates at rates up to 2000 Hz.

Acquisition occurs once on startup and whenever the HiBall sensor is moved beyond tracking range – outside the area of the ceiling, tilted past 90 degrees, farther than 10 ft. from the ceiling, or obscured from any line-of-sight readings. Acquisition proceeds independently for each HiBall sensor. Other sensors will continue tracking while one is re-acquiring.

Performance considerations

For optimum performance, keep in mind the following factors.

- The sensor should be no closer than 1.5 ft. (.46 m) to the Beacon Arrays, and no further than 10 ft. (3.05 m) from the Beacon Array for accurate tracking. Outside this height range, the tracker may not acquire or may be less accurate.
- The orientation range for the sensor is a full +- 180 degrees in azimuth (about the Z axis) and 0 to 90 degrees in elevation (about X or Y). If you tilt the sensor downwards below 90 degrees, it will see too few LEDs to continue tracking. The elevation range is reduced near the edge of the Beacon Array.
- If you occlude a HiBall sensor completely (by leaning over it, for example), it may see too few LEDs to continue tracking, or it may track only at a slow rate. Partial occlusion is generally not a problem.
- Avoid placing highly reflective objects near the HiBall sensor or the beacon strips. Strong reflections may reduce tracking accuracy.
- Acquisition will happen fastest if you hold the HiBall sensor still and upright while it is acquiring (while the red 'ACQ' is showing on the screen).
- The HiBall will acquire fastest at its *default acquisition height*. For most systems, this height is set to 5 feet up from the floor of your tracking environment. This distance can be customized in the tracker.cfg file (see section 6.2.2).
- Do not run any other applications on the HiBall server PC. If you run other applications on the PC, tracker performance will degrade significantly.
- The HiBall uses extremely high gain amplifiers and is therefore grounded to shield it from noise. This makes the electronics susceptible to static electricity in some high-static environments. Users should be properly grounded before handling the HiBall or CIB.
- If you get a shock when touching the system, it may stop tracking and require you to power down the CIB and restart. In some cases the software will detect and report 'hardware error' and automatically suspend tracking. In this case, uncheck the *suspend tracking* checkbox on the control panel. If tracking does not resume, power down the CIB and restart.
- Some types of lights affect HiBall tracker performance. If you see excessive jitter, try turning off lights in the environment, especially any lights directly behind the beacon strips.

3.2 Running client applications

Once you have the HiBall server running and generating measurements, you can start a client application to receive those measurements. You can stop and restart client applications at any time while the HiBall server is running. Connections to the HiBall server will be established (or re-established) automatically by VRPN. The next section describes how to create your own client applications using VRPN. Section 4.1.6 describes sample client applications included with the HiBall system.

4 Application Interface (VRPN)

The principal interface to the HiBall tracker is through the Virtual Reality Peripheral Network (VRPN) library. VRPN provides client-server communication, among a variety of VR components, over Ethernet connections.

VRPN is the recommended interface to the HiBall Tracker for several reasons:

- It provides a common interface to different trackers as well as interfaces to many other devices.
- It provides automatic timestamps, clock synchronization, record-to-file and replay-from-file
- It provides support for multiple clients connecting to a single device.

VRPN provides optimum performance and flexibility when interfacing to the HiBall tracker. VRPN was developed at the University of North Carolina at Chapel Hill and is supported by 3rdTech. Additional information about VRPN can be found at

http://www.cs.unc.edu/Research/vrpn/

4.1 VRPN

This section will guide you through installing VRPN and integrating it with your application. (We do not fully replicate the VRPN documentation, which is available both at the site listed above and on the HiBall Tracker CD.)

4.1.1 Install VRPN Client Software

To begin, you will install VRPN onto your **client** computer on which you will run your HiBall applications.

Note: Do not install it on the HiBall PC, which must ONLY run the HiBall server.

If you already have the current version of VRPN installed (as of the time of this manual printing, version 7.09) you do not need to re-install it. You can obtain updated versions of VRPN at the web site listed above.

The HiBall Software CD includes:

- VRPN (Virtual Reality Peripheral Network) files and documentation. VRPN has been tested on the following architectures: SGI/Irix, PC/Win32, PC/Cygwin, HP700/HPux, Sparc/Solaris, PC/Linux.
- Sample HiBall tracker application code for VRPN under Windows
- A backup copy of the HiBall Server software, which is already installed on the HiBall PC.

To install VRPN

1. Copy the VRPN folder from the HiBall Software CD to the computer running your application, and build the VRPN library and the test applications. Refer to the main page of the VRPN documentation for details on compiling and follow the instructions there.
2. Connect the HiBall Tracker PC Server to your local network and set its network properties appropriately. If you change the machine name (default is 'HiBall') then you will need to change HiBall configuration files – refer to Section 6.2. Set the time zone on the HiBall Tracker PC Server appropriately for your location. A mismatch in time zones between computers on your network may cause VRPN errors.

The VRPN documentation (on the web site and on the CD) includes details on how to write VRPN applications for any tracker. The following section briefly describes how to use the HiBall Tracker with VRPN.

4.1.2 Writing a VRPN/HiBall client application

VRPN devices are referred to by a device name and a machine name, as in *device@machine*. HiBall tracker devices will be named *Tracker0@hiball*, where *hiball* is the name given to the HiBall PC. You can use an IP address in place of machine name, and in some cases VRPN will establish connections faster if you give an IP address. (Make sure you capitalize the T in 'Tracker0' – case is significant for VRPN device names.)

Your applications should include the code listed in Figure 10. For more details see the section of the VRPN manual on client software and on *vrpn_Tracker_Remote*. Also see the sample tracker client file in the VRPN source tree.

```
#include <vrpn_Tracker.h>

// create a tracker object
vrpn_Tracker_Remote Tracker("Tracker0@hiball");

// Register a callback to process records
Tracker.register_change_handler(NULL, handle_tracker);

// program's main loop
while (!done)
{
     // This calls the tracker driver, which will call
     // your handler function as necessary
     Tracker.mainloop();
}
```

Figure 10 C/C++ Code to include in HiBall/VRPN Applications

The HiBall tracker operates as a standard *vrpn_Tracker_Remote* class. You communicate with it as you would with any other VRPN-supported tracker. The application creates a new vrpn_Tracker_Remote class and registers a callback function to process records from the device. In the main loop of your code you call the tracker's *mainloop( )* function to generate a record.

A sample callback function is illustrated in Figure 11. The callback function gets called every time a new record has been received from the HiBall server for any sensor.

```
void VRPN_CALLBACK handle_tracker(void *userdata, const
     vrpn_TRACKERCB t)
{
     printf("handle_tracker:  Sensor %d is now at
            (%g,%g,%g)\n", t.sensor,
            t.pos[0], t.pos[1], t.pos[2]);
}
```

11 Sample VRPN Callback Function

The client will receive records from the HiBall server at the rate specified in the VRPN configuration file. This rate is displayed on the 'VRPN Server' tab on the server control panel. You can change this rate by changing the VRPN configuration file (see Section 6.2). The default is typically 72 Hz. This rate should be no less than your program's display or computation loop.

If your program's main loop runs significantly faster than the VRPN update rate for the device (and you do not wish to change the server update rate), you may wish to ensure that your callback always gets a new record each time your program goes through its main loop. See the vrpn_Tracker_Remote documentation for code to do this.

Record Format

The callback function you create receives a tracker record with the format specified in Figure 12.

```
typedef struct {
      struct timeval  msg_time;  // Time of the
                                 // report
      long   sensor;            // Which sensor is
                                // reporting
      float  pos[3];            // Position of the
                                // sensor
                                float  quat[4];
                                       //
                                Orientation of
                                // the sensor
```

Figure 12 VRPN Tracker Record Format

- The **pos** and **quat** fields give the position and orientation of the HiBall sensor with respect to tracker coordinates.
- The position (translation) is returned as floating-point values in meters (X, Y, Z).
- The orientation quaternion (rotation) is returned as floating-point (X, Y, Z, W). VRPN's quaternion convention is (X, Y, Z, W), where W is the scalar component, and X, Y, Z specify the axis of rotation. The whole quaternion vector is normalized. VRPN provides functions to convert from quaternions to Euler angles (additional information is in Section 4.1.4).

4.1.3 Coordinate Systems

The 'pos' and 'quat' fields returned in the VRPN Tracker record form the 'sensor coordinates to tracker coordinates' transformation, with the translation first, followed by the rotation. That is, this transformation will take points in the sensor coordinate frame to the tracker coordinate frame.

The sensor coordinate frame is defined with +Z up, +X along the HiBall tether, and +Y ninety degrees counter-clockwise from +X when viewed from above (X, Y, Z form a right-handed coordinate system). The origin is at the center of the base of the HiBall sensor. Figure 13 illustrates the coordinate system.

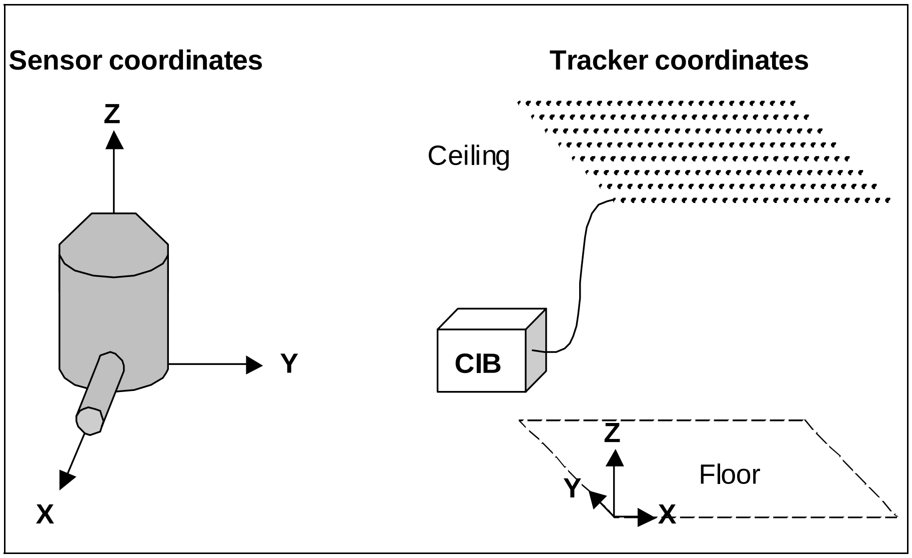

Figure 13 Coordinate Systems for the HiBall Tracker.

The tracker coordinate frame has +Z up, and X and Y along the edges of the Beacon Array configuration to form a right-handed coordinate system (X and Y are marked on your ceiling map diagram for reference.) The origin of the tracker coordinate frame is on the floor directly beneath the first LED on the first strip in Bank 0. This point is marked with a circle in your ceiling map diagram. Note that the height of your ceiling, as specified in the ceiling map editor and indicated in the ceiling map diagram, determines the Z-point of the origin. If you specify a height of zero, the origin will be at the height of the LEDs.

In your application, typically, you will want to introduce additional coordinate systems for convenience. We recommend maintaining a coordinate-system tree as in Figure 14, at least conceptually.

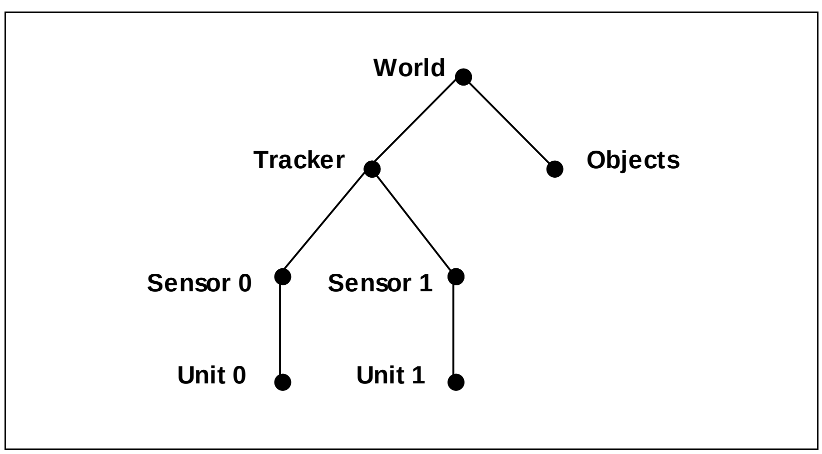

Figure 14 Coordinate Systems for Tracking.

Each dot in the tree is a coordinate system frame. The lines between them represent transformations between two coordinate systems (and these can be composed, inverted, etc.).

The HiBall Tracker returns sensor-to-tracker (or 'tracker-from-sensor') transformations. The other transformations are typically needed for VR applications. VRPN has an optional facility to maintain tracker-to-world and unit-to-sensor transformations automatically. You can define these in a file called *vrpn.cfg*. This is described in the *vrpn_Tracker_Remote* section of the VRPN manual.

Alternatively, you can maintain these extra coordinate systems in your code. A tracker-to-room transformation is useful if you want to redefine the origin for your tracked space. A unit-to-sensor transformation (e.g., head-to-sensor or hand-to-sensor) enables you to easily go from HiBall sensor coordinates to a meaningful coordinate frame on a head-mounted display or hand-held device. Section 4.1.5 describes the offsets for the HiBall stylus.

Using a scheme like this simplifies drawing objects attached to different frames. To attach an object to the sensor's position, for example, you enforce a constraint about the sensor-to-object (or unit-to-object) transformation.

For more information about using coordinate systems for tracking and virtual reality, we recommend the following references:

Foley, J.D., A. van Dam, Steven K. Feiner, and John F. Hughes (1990). *Computer Graphics: Principles and Practice, 2nd edition.* Addison-Wesley Publishing Company.

Robinett, Warren and Richard Holloway (1992). "Implementation of flying, scaling, and grabbing in virtual worlds." In *Proceedings of the 1992 ACM Symposium on Interactive 3D Graphics*, 189-192.

Robinett, Warren and Richard Holloway (1995). "The Visual Display Transformation for Virtual Reality." *Presence,* 4(1), 1-23.

4.1.4 Quaternions

The HiBall server and VRPN use the quaternion format for rotations. A note about quaternions (excerpt from the VRPN manual):

> The quaternion angle representation stores the orientation as a four-vector, where the first three values specify the axis around which the rotation occurs and the fourth specifies the amount of rotation. The whole vector is normalized. This matches UNC's *quatlib* format. Quatlib source code is included in recent VRPN releases; it shows up in a *quat* directory, alongside the *vrpn* and *vrpn_html* directories.
>
> For those not familiar with quaternions, they are a concise and efficient way of describing rotations and orientations of three-dimensional objects. (Two good references for this subject are Ken Shoemake's 1985 SIGGRAPH papers "Quaternion Calculus for Animation" and "Animating Rotation with Quaternion Curves" in the '85 proceedings.)

The library is built on Ken Shoemake's code (as presented in the appendix of the first paper listed above) and implements the most common quaternion functions, as well as some more obscure ones. In particular, there are conversion routines between vectors, matrices and quaternions, as well as various vector and matrix operations.

To convert between quaternions and Euler angles, you can use functions provided with the VRPN auxiliary library quatlib. The follow sample code will do this conversion.

Euler angles to quaternion:

```
#include <quat.h>

q_type q;
double yaw;   // about Z
double pitch; // about Y
double roll;  // about X

// set values of yaw, pitch, roll
// convert
q_from_euler(q, yaw, pitch, roll);
```

Quaternion to Euler angles:

```
#include <quat.h>

q_type        q;
q_matrix_type matrix;
q_vec_type       yawPitchRoll;

// set value of quaternion q

// convert
q_to_col_matrix(q, matrix);
q_col_matrix_to_euler(yawPitchRoll, matrix);
```

4.1.5 Using the Stylus

Offsets to stylus tip

The HiBall Tracker stylus (Figure 15) consists of a handle with a 'trigger' button and an interchangeable metal probe. The probe (3/8"-24 thread) mounts at a 45-degree angle down from horizontal.

The position offset from HiBall sensor coordinates to the **base** of the screw-in probe is

[X, Y, Z] = [0, -71.113 mm, -7.428 mm].

The position offset from HiBall sensor coordinates to the **tip** of the probe is

[X, Y, Z] = [0, -167.335 mm, -102.808 mm].

(These are nominal values derived from the manufacturing specifications; for more precise values there is a calibration procedure; contact support@3rdtech.com for details.)

Figure 15 HiBall Stylus with Long Probe

Communicating with stylus buttons

You communicate with stylus buttons through VRPN in the same way as with the tracker reports. Create a *vrpn_Button_Remote* device that connects to "Button0@HiBall", and register a callback for the buttons. Your callback function will receive a record from VRPN every time a button is pressed or released. The callback function should look like the following:

```
void VRPN_CALLBACK handle_button(void *userdata, const
      vrpn_BUTTONCB b)
{
     // HiBall Stylus buttons:
     // b.button indicates HiBall/stylus tether
     // b.state indicates button down (1) or up (0)

        printf("Button state %d from hiball %d\n",
                b.state, b.button);
}
```

To operate the stylus as a '3D object digitizer', have your tracker callback keep a copy of the latest tracker report and when you get a 'button down' event, take the latest tracker report as the stylus position. This is illustrated in the sample application *stylus*. Note, also, that both records have timestamp information. You can check these if button-tracker synchronization is a concern (in an application with a slow main loop, for example).

Using the stylus for digitization/measurement

For measurement/digitization applications, you will typically want to use HiBall system settings that maximize absolute accuracy. This can be achieved by running the system with a saved, autocalibrated ceiling map (see Section 6.3) and autocalibration off (see Section 6.2.3). Note that this will provide the highest absolute accuracy at the expense of some of the 'smoothness' of the output. Applications for graphic display on monitors, projectors, or head-mounted-displays will typically want to trade off this peak absolute accuracy for smoother readings by running the system with autocalibration on.

4.1.6 Sample VRPN client applications

Along with VRPN, sample VRPN client code is included on the HiBall client software CD. The binary files for these programs will run as-is on most Windows PCs. The source files are included, and should compile as-is under Windows using Microsoft Visual C++ or on other platforms with minor changes. They are intended to be simple enough to be modified for other platforms easily. Some of these programs require VRPN, OpenGL, and GLUT (the OpenGL Utility Toolkit). The library and include files for VRPN and GLUT are provided on the CD; newer versions may be available on the respective websites

- GLUT is available from SGI at http://reality.sgi.com/opengl/
- VRPN is available at http://www.cs.unc.edu/Research/vrpn

The GL files should come with the compiler or the graphics card driver.

In order to compile and link these applications, you will need to define an environment variable called HIBALL_ROOT that specifies the path to your client's Hiball directory. The include files for VRPN, etc, are assumed to be in $(HIBALL_ROOT)\include and the libraries are assumed to be in $(HIBALL_ROOT)\lib\{Release,Debug}, etc.

Sample graphical applications:

- *simpleApp* – displays a wire frame representation of the room and coordinate axes at the tracker origin and at the origin for each HiBall. This demonstrates how to draw objects at the sensor positions and how to draw a head-tracked view.
- *stylus* – demonstrates how to use the HiBall and stylus to digitize points. This program displays a wire frame room (similar to that in simpleApp) and coordinate axes at the HiBall position. A sphere is drawn at the stylus tip position. Each stylus button click generates a marker point in the environment. Point locations are also saved to a file. In 'stream' mode, points are generated as long as button is held down. This app can also be used to calibrate a stylus tip.
- *dials* – this program is useful for measuring tracker performance. It provides graphical display of tracker reports and computes standard deviation of reports (to estimate noise when the HiBall sensor is kept still).

Sample text-only applications:

- *textApp* – a simple application that display tracker records once every few seconds and button records as they happen
- *record* – this application will record tracker position and orientation data to a file at the VRPN update rate. The output format is as follows, where time is in seconds, X, Y, and Z are in meters, and Yaw, Pitch, Roll are in degrees:

```
time X Y Z Yaw Pitch Roll
```

Note: as always, you should not run these client applications on the HiBall server itself because it will slow down the tracker. (Running text-only demos on the HiBall PC may not cause serious problems.)

5 Troubleshooting

5.1 Hardware problems

- **Some LEDs on the ceiling do not blink.** If a region of the ceiling doesn't appear to blink, run *ledtest* to check all LEDs; then check connections. You may need to test parts of the ceiling in small increments in order to isolate the strip at which the problem begins.
- **HiBall server PC screen goes blank.** Check that the screensaver is disabled (in the Display control panel under Settings). The screensaver may lock up under Windows while CPU-intensive programs are running.
- **HiBall server is slow or prints multiple timeout messages.** Check that no other applications are running on the server PC. You must run client tracker applications on other machines.
- **"Out of disk space" errors on the HiBall PC.** The HiBall PC requires disk space in which to store log files (typically in C:\HiBall\logs). Remove other applications from the HiBall PC – this machine must only run the HiBall server or the tracker will not function properly.

5.2 Error messages

- **"InitPortIO: Couldn't access giveio device"** - Check that the parallel port cables are connected properly to the correct ports. Check that the CIB is powered on.
- **"ERR_RX_TIMEOUT" or other "EPP timeout" messages** – Check that the correct number of HiBall sensors is connected and that the CIB is powered on.
- **"ERR_RX_CKSUM" or other "ERR_RX" messages.** Check that parallel port cables are connected properly to the correct ports.

5.3 Tracking performance

- **Tracker is slow acquiring or always displays red "ACQ".** Try to keep the HiBall upright and still at a height of 5 feet off the floor, or at the height specified in the configuration file (see section 6.2.2); acquisition will be fastest under those conditions. Check, using the IR camera and TV, whether any LEDs are blinking on the ceiling. If no LEDs are blinking, shutdown the server, power-cycle the CIB, and restart. If LEDs blink but the system still will not acquire, check that your ceiling map height (in the ceiling map file) corresponds to your physical ceiling height.
- **LEDs do not blink.** If no LEDs blink when the HiBall server is running, power-cycle the CIB and run *ledtest*. Step through all LEDs to verify that they work.
- **Jitter in tracker reports.** We have found that certain lights interfere with HiBall performance. Try turning off lights in the environment, especially lights directly behind Beacon strips. Try the post-filtering tools on the VRPN control panel. We recommend exponential post-filtering set at 90. If the problems continue please contact 3rdTech.

5.4 Support Contacts

Email: support@3rdTech.com

Phone: (919) 361-2148

6 Customizing the HiBall Tracker

6.1 Changing the ceiling configuration

The HiBall-3X00 system comes with a standard ceiling map that fits your initial configuration. You can customize this map to your meet your requirements. We recommend connecting and testing the pre-configured map first before you make any customizations.

Customizing the map will enable you to

- Skip over obstacles in the ceiling – smoke alarms, sprinklers, vents, etc.
- Change the dimensions of the ceiling (to fit into a narrower space or around a corner).

The software requires Beacon strips to be laid out on an 8-inch by 24-inch grid (except in special cases – see Section 6.1.2). The ceiling map editor lets you change the order and arrangement of strips on this grid. It generates a ceiling map file that specifies for the HiBall server how the strips are connected.

6.1.1 Running the ceiling map editor

The ceiling map editor is located on your server PC in the C:\HiBall\bin directory. Run the program as follows:

makemap -i <input file> -o <output file> -hf <ceiling height in feet>

Run this program on the HiBall server PC (when the HiBall server is not running), or on your own client PC

A note about arguments:

- You can specify the same file for both input and output.
- The height argument only needs to be specified if you want to change it; otherwise it will default to the value that's in the input file.
- If you specified no input file or ceiling height then the program will start with a 1-strip ceiling at 8 feet high.
- If you give no output file name then the program will write to *ceiling.map* or to the input file, if you gave one.
- If specified, the input file must be an original *unedited* map file; makemap cannot load files that have been auto-calibrated or previously edited by hand.
- You can specify the ceiling height in meters instead of in feet by using the flag '-hm' rather than '-hf'

To start a new map file from scratch use 'makemap -o file.map –hf height' – it will start with the default 1-strip ceiling at 'height' feet.

Use the extension *.map* for ceiling map files.

Editing and saving the ceiling map

When you run this program it will bring up a graphics window and a text DOS window. Look in the text window for error messages and status information.

The graphics window will appear as follows (this is the default screen when the program is started without an input file).

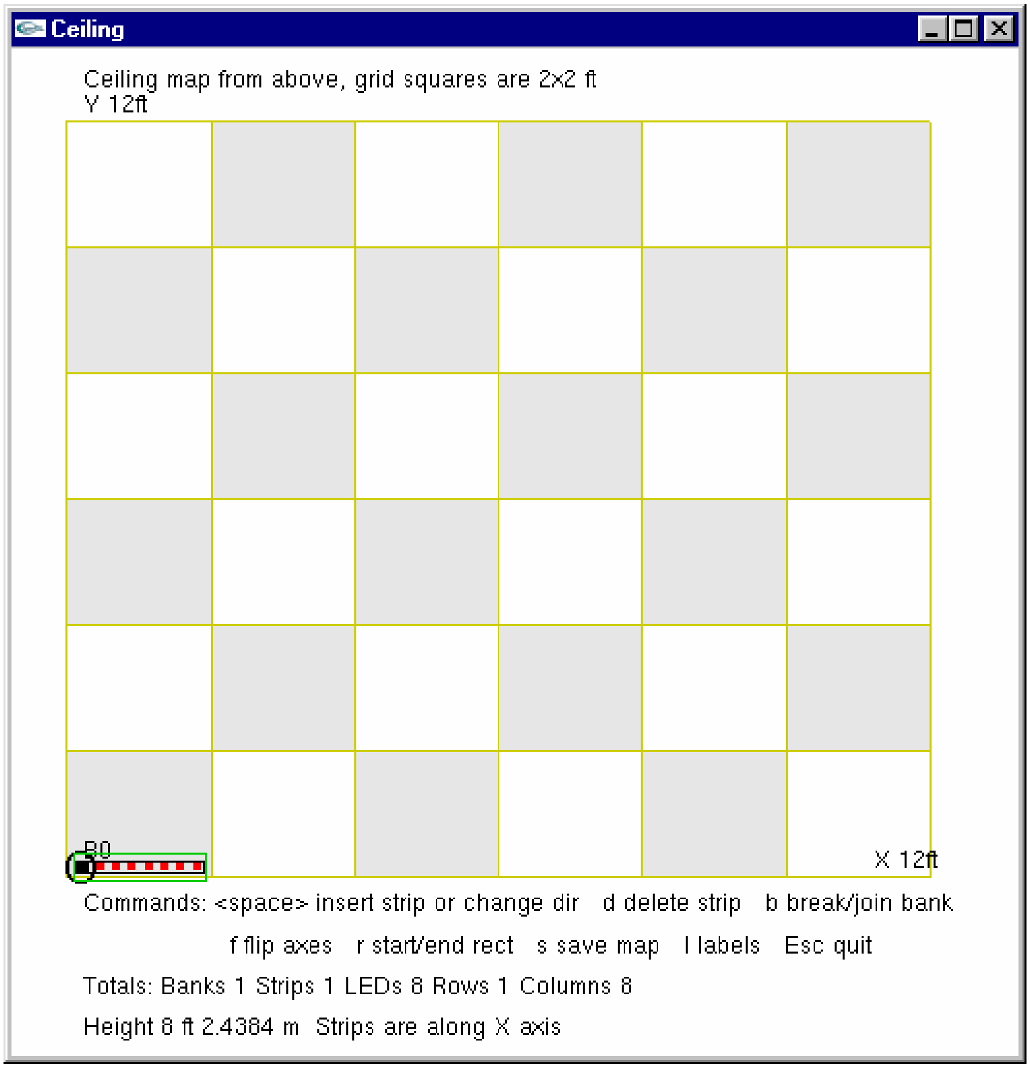

Figure 16 Ceiling map editor.

The grid indicates an array of 2 ft. x 2 ft. ceiling tiles. It represents the ceiling as seen from above. The green rectangle indicates a cursor position. You can move this cursor with the arrow keys on the keyboard.

The workspace will adjust according to the size of the ceiling you define. 12 ft. x 12 ft. (6 x 6 tiles) is the minimum size. The maximum size is currently 40 ft. x 40 ft. (20x20 tiles). Each strip is represented by a rectangle with 8 dots inside it. The first dot, which is black, shows the location of the 'In' end of the strip. This is referred to here as *LED 0* – the first LED on the strip. The other 7 LEDs are displayed in red.

Strips normally point left-to-right or right-to-left, on the ceiling map editor's screen. To toggle this direction, press the space bar over the strip. The first strip must always have LED 0 in the corner (you can't change the direction of this strip). This position defines the origin of tracker coordinates (marked with a large circle on the screen). (See section 4.1.3 for details on tracker coordinate systems.) Note that the lines indicating cables may be drawn overtop of strips if you have the direction reversed. Be sure to wire them in the correct manner (look at the dots on the ends of the strips and the strip numbers to be sure of the connection order).

To add strips to a ceiling, move the cursor to the next location, and press the space bar to add a strip. To change that strip's direction, press space again over the selected strip. Move the cursor to the next strip location and continue - press space to add another strip. Our convention for laying out strips is to continue one row lengthwise across the whole ceiling and back, etc. as shown in Figure 4, though you can lay the strips out differently if you prefer (remember that you may need new strip-to-strip cables of different lengths if you change the ceiling layout).

There is a shortcut for laying out large rectangular ceilings. Move the cursor to the lower-left corner of the rectangular area and hit the 'r' key. Then move to the upper-right corner and hit 'r' again. Strips will be added to fill the rectangular region – make sure the connectivity is as you intended.

Lay out your entire ceiling (108 strips for a 12 x 12 ft. ceiling). Use the 'l' command to see labels on the strips. This adds a 'bank/strip' label next to each strip, which will be useful when making physical connections.

If you have multiple banks, hit the 'b' key over a strip to make it the first strip of a new bank. The first strip of each bank is labeled, e.g. B0, B1, etc. Even-numbered banks will be displayed in red; odd-numbered banks will be displayed in blue. Keep cables in mind when you choose where to start new banks. Figure 15 shows a typical 3-bank installation for a 20x20 ft. ceiling (10 rows per bank, 100 strips per bank).

To delete strips from the map, hit the 'd' key. The editor will delete the last strip at the cursor position. You can delete strips from the middle of a rectangular region if necessary.

Summary of editing commands

- **Arrow keys –** move cursor (green box) over strip locations
- Space (over empty location) - add strip at cursor
- Space (over filled location) - change strip direction
- **d –** delete strip at cursor
- **r** – start or end a rectangular region to be filled with strips
- **b –** bank select. Make strip at cursor start a new bank or join previous bank.
- **l –** display labels at strips
- **R –** reload map from input file
- **s –** save map to output file
- **v** – toggle output between map file versions 1 and 2. If your HiBall software version is at least 1.7, you will be using version 2 map files.
- **f –** flip X and Y axes Necessary only for some nonstandard ceiling tiles – see the note below.
- **Escape key –** exit program (NOTE: this does not do a save).

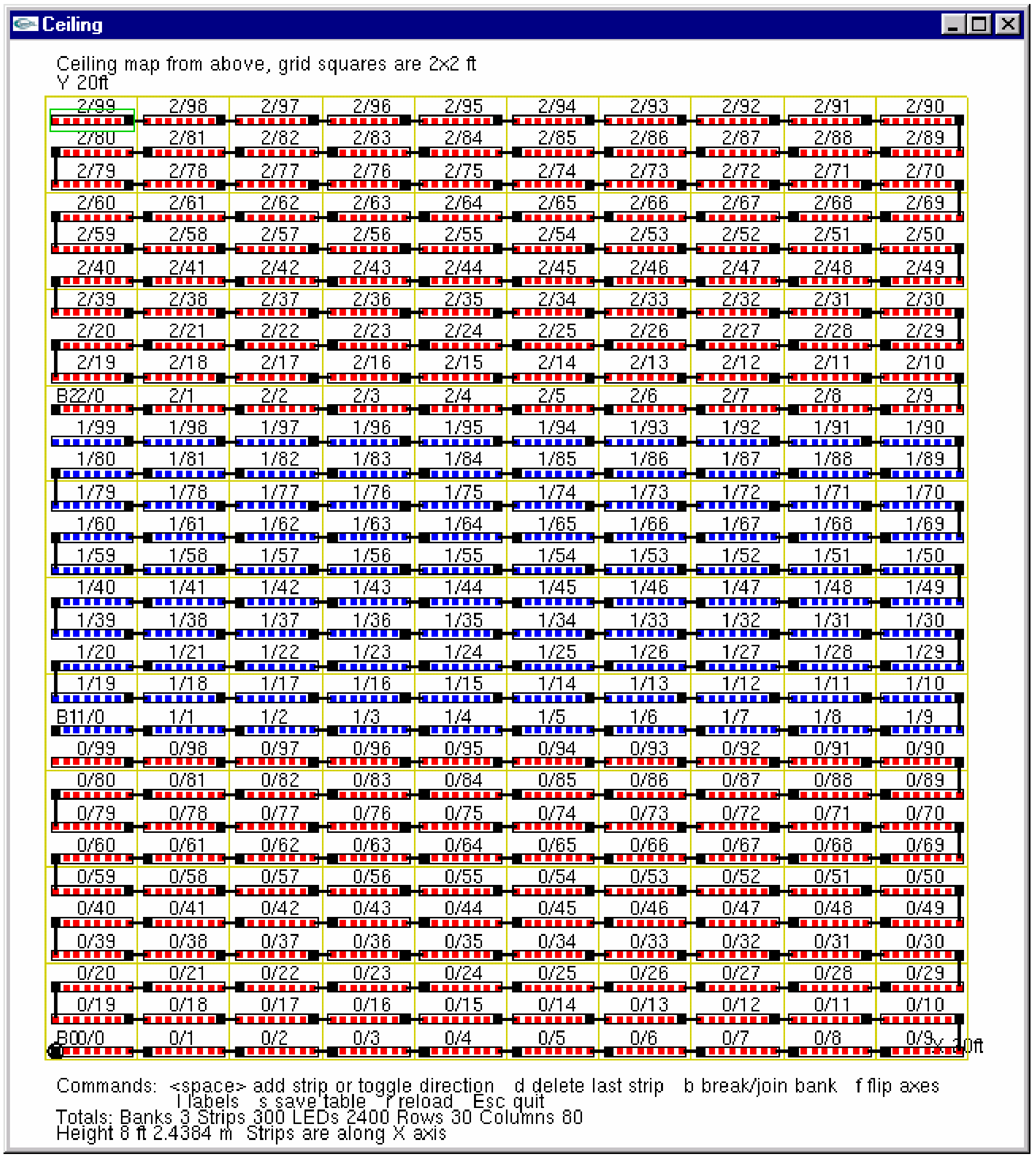

Figure 17 Typical 20 ft. x 20 ft. Ceiling Configuration as Three Banks.

6.1.2 Considerations when changing the ceiling map

- Strips must be aligned on an 8-inch by 24-inch grid. In special cases you may differ from this slightly – see section 6.1.4.
- Note that the ‘add at cursor’ method of adding strips makes the layout appear more flexible than it really is. Skipping over occasional strips is okay, but if you skip too many the tracker will not function properly. The system needs a dense array of Beacon Arrays to function properly. The tracker will not function properly if you try to change the density of strips (by skipping entire rows or columns, for example).
- You may connect up to 255 strips per bank, and up to 8 banks. We recommend keeping less than 128 strips per bank unless necessary for a large system that requires all 8 banks.

- ❑ Keep cable lengths short where possible. We recommend following the end-to-end scheme described above.
- ❑ CIB-to-strip cables are different from strip-to-strip cables. Contact 3rdTech for additional cables.
- ❑ The HiBall sensor must be between 1.5 feet and 10 feet from the ceiling to track. When doing head tracking the ceiling height typically should be no lower than 8 feet and no higher than 15 feet.

In some cases you will need to skip a strip or tile in your ceiling (to avoid a smoke alarm, sprinkler, or vent, for example).

You can skip spaces in the ceiling map by placing the cursor accordingly in the editor, or by deleting strips from a filled region. Figure 18 shows an example map that skips over an entire 2 ft. x 2 ft. tile in one location, and a single strip in another location. Note that you may need extra strip-to-strip cables of different lengths if you customize your map.

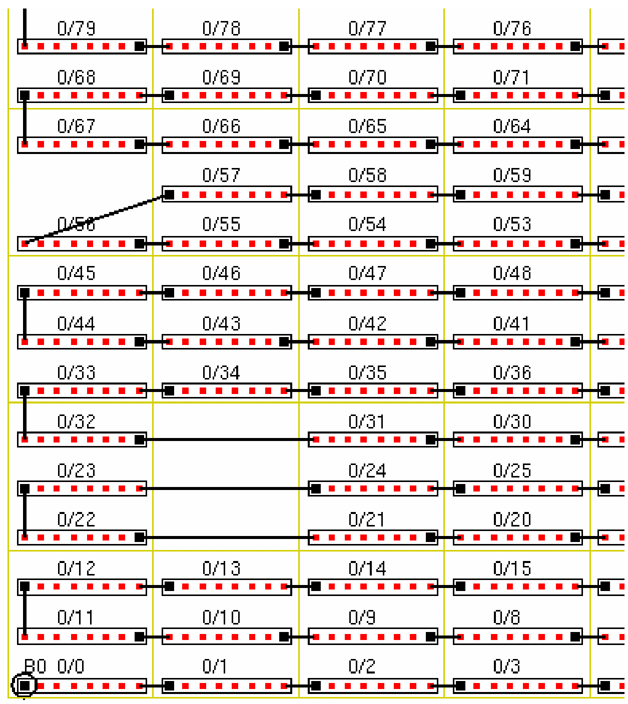

Figure 18 A portion of a ceiling map showing strips deleted to avoid obstacles.

Note for nonstandard ceiling tile dimensions: Ordinarily, with a 2 ft. x 2ft. tile drop ceiling, you should start the strip rows heading to the right, as shown above. X is always to the right, so strips are along X. This will not work if you have 2 ft. x 4 ft. tiles and they're oriented such that the 4 ft. space is along X (left-to-right in the editor) when you place the origin where you want it. In this case you will need to have strips going along Y (up-down in the editor). Use the 'f' (flip axes) command to do this.

If your ceiling is not a 'drop' ceiling, you can mount the strips by screwing them into wooden or other solid frames rather than placing them under ceiling supports. Note that you must always be sure that strips are positioned on an 8-inch by 24-inch grid. The software requires this constraint for tracking.

Power Distribution Box Location

The current implementation of the ceiling map editor does not provide information about the number or location of PDBs. Here are some guidelines for locating them in custom ceiling maps. Note that these are only guidelines – actual placements may vary with special configurations.

- ❑ If a bank has 36 or fewer Beacon strips you probably do not need any PDBs. In this case, the CIB-to-strip cable connects directly to the first strip in the bank.
- ❑ Each bank with more than 36 Beacon strips will need at least two PDBs – one connected between the CIB and the first Beacon strip (placed next to the first Beacon strip), and one at or near the end of the bank.
- ❑ Distribute PDBs evenly within a bank – but wiring convenience can also be taken into account. The goal is to have the first and last PDBs near each end and the inline PDBs distributed evenly as possible with 30-60 strips per PDB. See Figure 4 for a sample placement for 108 Beacon strips.
- ❑ The PDBs in a single bank get connected in a daisy chain to the first PDB in that bank with Power Distribution cables. They do not get connected to PDBs in other banks.

If you have questions about a particular custom configuration please contact 3rdTech support.

Ceiling height

The height parameter defines the Z=0 point for tracker coordinates. Our convention is to set height equal to the height of the LEDs above the floor. With this convention, the tracker will return Z=0 when the HiBall is on the floor. The default value for ceiling height is 10 feet (3.048 m). You can leave the height at the default value and adjust the Z parameter in your software if you prefer. To change the height of a ceiling map that you've already created, run *makemap* with your new height and resave (e.g. run '*makemap -i file.map -hf newHeight*', hit 's' to save, then quit). The new height should now show in the display. You can also examine the ceiling map file itself.

Placing strips in the ceiling

There is some tolerance in the software for error in strip placement – up to approximately ½ inch (1.3 cm). The software's LED autocalibration will attempt to correct for this over time. Errors larger than this may not be corrected and will degrade performance. Remember to power off the CIB when changing ceiling connections.

6.1.3 Enabling the new ceiling map in the tracker configuration file

The tracker configuration file specifies which ceiling map to use. Edit the file to point to your new map file.

6.1.4 Changing the Beacon Grid Spacing

If necessary for your ceiling you may alter the 8" x 24" grid spacing of Beacon strips. Use this functionality for minor changes only (e.g., due to metric vs. English units).

Grids with spacing other than 8” x 24” have not been tested. Changing the beacon spacing may change the performance characteristics of your HiBall Tracker system.

To change the strip spacing:

Change the spacing in the ceiling map file using “makemap”. Makemap places strips on an 8” x 24” grid by default. To change the grid spacing, specify the new row and column spacing on the command line when you execute makemap as follows (note: this is in *inches*, not meters).

makemap -i input –o output –hf heightFeet –r stripRowInches
–c stripColInches

6.2 Customizing the HiBall Server

6.2.1 Overview of configuration files

The following configuration files are used in the HiBall tracker. These files reside in your HiBall configuration directory (typically C:\HiBall\config\ -- see your HiBall installation information document for the exact location). These files are listed in a ‘top-down’ fashion – each file references only files below it. If you edit any file you may need to edit the files above it. Most files can be edited with the *wordpad* application, except where noted.

- ❑ **VRPN Configuration File** (e.g. ‘vrpn.cfg’). This is the top-level configuration file for the HiBall VRPN server. It contains the VRPN device names for the tracker and button servers, and parameters for VRPN update rate, tracker filtering and prediction.
- ❑ **Tracker Configuration File** (e.g. ‘tracker.cfg’). This file lists the HiBall sensors that are connected (by their configuration files), the ceiling map, and other details specific to the PC host.
- ❑ **Ceiling Map File** (e.g. ‘12x12.map’). This file describes the strip arrangement and ceiling height. You can create or edit ceiling map files with *makemap* as described in Section 6.1.
- ❑ **HiBall Configuration File** (e.g. ‘hiball3009.cfg’). This file describes HiBall-specific configuration information. (One for each HiBall sensor.) **DO NOT EDIT THIS FILE.** The configuration for this particular HiBall Sensor was specified at the factory.
- ❑ **HiBall Calibration File** (e.g., ‘h3009dtab.mat’). Calibration tables (one for each HiBall sensor). **DO NOT EDIT THIS FILE.** The calibration tables for the specific HiBall Sensor were determined at the factory.

The following sections describe common changes to the configuration files.

6.2.2 Changing the HiBall Sensor arrangement

If you want to add a new HiBall sensor, or change the arrangement of HiBall sensors (e.g., to create a configuration that uses only one HiBall instead of two), change the Tracker Configuration File (or create a new one). Edit the ‘tether’ lines in the Tracker Configuration File, e.g.

```
tether 0 C:\config\hiball3009.cfg
```

This line specifies the tether (HiBall) port and matching HiBall Configuration File. Make sure you have the correct HiBall connected to the port (check the serial number on the base of the HiBall). If there is more than one tether line in the Tracker Configuration File, the first will refer to sensor 0 in VRPN reports, and the second to sensor 1 in VRPN reports.

Note that if you create a new Tracker Configuration File you will need to change your VRPN Configuration File to refer to it (or create a new VRPN Configuration File and shortcut for that Tracker Configuration).

You can use an optional third parameter here to set this HiBall's *default acquisition height*, in meters *below* the ceiling. For example:

```
tether 1 C:\config\hiball3012.cfg 1.5
```

This line tells the tracker that the default acquisition position for the HiBall on tether one will be 1.5 meters below the ceiling. Whenever that HiBall needs to acquire, the system will begin by assuming that position, and then adjusting its estimate until acquisition is successful. This means acquisition will be fastest when the HiBall is held upright and still at a distance of 1.5 meters below the ceiling. The HiBall will still acquire at other heights in a slightly longer period of time.

If no parameter is given here, the system will calculate a distance equal to 5 feet off your floor (the floor location is determined by the *ceiling height* set in the map file), and use that as the default acquisition height.

6.2.3 Changing configuration files

Customizations to the VRPN Configuration File

The VRPN Configuration File contains a line each for the VRPN tracker and button devices:

```
vrpn_Tracker_Hiball Tracker0@hiball
    c:\HiBall\config\tracker.cfg 72 0 0 0 0 90
                 vrpn_Button_Hiball Button0@hiball 1 0x378
```

You should not change the parameters to the button line in the VRPN Configuration File. Some fields in the tracker line are editable. The fields in that line are as follows:

- *'vrpn_Tracker_HiBall'* – VRPN device type (do not change this).
- *'Tracker0@HiBall'* – VRPN device name (do not change this).
- Tracker Configuration File – the path for the file.
- *Update rate (Hz)* – the rate for sending reports from the VRPN server to client applications. A typical value is 72. This should be slightly higher than your display (or computation) rate so that you will get one record per frame.
- *Prediction time (ms)* – typical value is 0. Should be no more than 25.
- *Averaging post-filter time (ms)* – typical value if used is 20 ms.
- *'0'* – this parameter is no longer used, but is retained for backwards compatibility – please leave it at 0.
- *Median filter window (number of records, 3 to 23)* – specifies the width of a median filter to apply to tracker measurements to remove outliers.

- *Exponential averaging post-filter constant (0 to 100)* – typical value is 90. Determines the degree of exponential post-filtering to be added for smoothing the tracker measurements.

You can specify only one type of post-filtering or prediction. The values for the other filters must be zero. To apply an averaging post-filter of 20 ms, the last five fields would be ‘0 20 0 0 0’. To apply an exponential averaging post-filter with filter constant 0.95, you would use ‘0 0 0 0 95’.

Note that some of these fields can also be changed interactively in the VRPN Server Control Panel while the tracker is running (see Section 4.1).

Customizations to the Tracker Configuration File

You may wish to edit the following lines in the Tracker Configuration File (note: all keywords should be all lower-case)

- tether <0|1> C:\hiball\config\hiball3XXX.cfg [distance]- Choose tether ports and HiBall sensors, and optionally specify acquisition distance (as described in previous section).
- autocalibrate <on|off> - Use this to turn LED position autocalibration on/off (see Section 6.3 for more on autocalibration).
- ‘logdir <path>’ - Change the path for VRPN Server log files.
- ‘ceilingmap <mapfile>’ - Choose a ceiling map.
- ‘multimodel <on|off>’ – enable/disable multimodel switching (see Section 6.4).a
- ‘multimodelt <vel> <buffer>’ – translational velocity and threshold for multimodel switching.
- ‘multimodelr <vel> <buffer>’ – rotational velocity and threshold for multimodel switching.

6.3 Customizing Beacon Autocalibration

The Beacon Autocalibration feature will automatically adjust for errors in strip position that result from how the strips are positioned initially (or even from motion in the ceiling during operation). Autocalibration will correct for these errors as you move the HiBall sensor around. Each time it views an LED, it improves its estimate of that LED’s position. Typically, any large errors in LED positions will be corrected within 30 seconds of normal tracking. Within 3 minutes, the system will reach its optimal estimates of LED positions and will henceforth make little further improvement.

For maximum accuracy, we recommend that you run autocalibration as a separate procedure after installation and save a calibrated ceiling map to start tracking with in subsequent runs. This will allow the ceiling to begin with a good estimate of LED positions and will enhance accuracy during the first few minutes of each subsequent run. The following sections describe how to do this.

Autocalibration status information

The ‘Beacons’ tab on the HiBall control panel (see Figure 19) shows the status of autocalibration:

- Whether autocalibration is on or off.

- ❑ The average ‘beacon correction factor’ across all LED beacons only if autocalibration is on). This is an estimate of uncertainty about beacon positions. The smaller this number is, the more certain the system is of the beacon positions. This value starts at 3, and will typically decrease to less than 0.3 after 2 or 3 minutes of tracking.
- ❑ The number of beacons that have not yet been seen by the tracker. The system can only correct beacons positions if it sees them. Thus you should make sure this number has decreased to zero if you are generating a precalibrated map.

Click the ‘update statistics’ button to update the count of unseen beacons and the beacon correction factor.

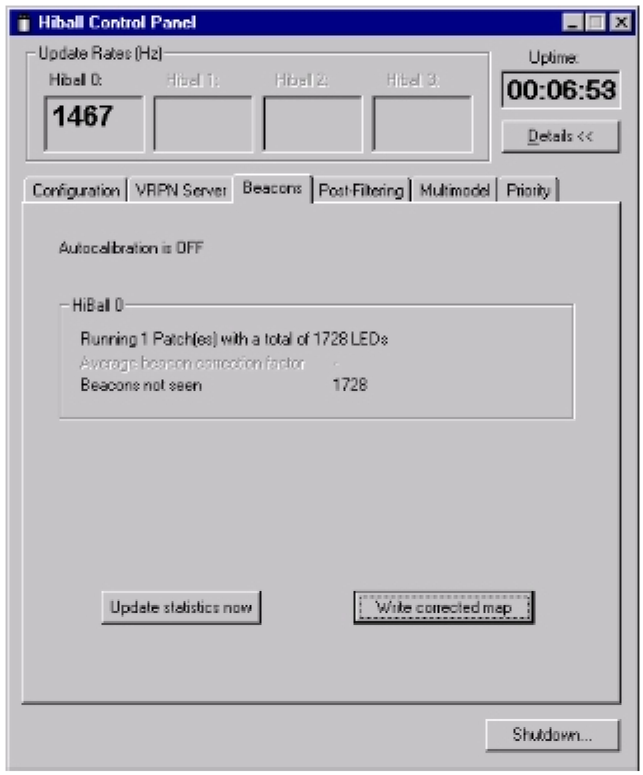

Figure 19. Beacon calibration tab in the HiBall Control Panel.

Creating and saving a calibrated ceiling map

To generated a corrected map:

- ❑ If you have more than one sensor, comment out the second sensor’s line in your *Tracker Configuration File* (described in Section 6.2.1 and 6.2.3) by placing a ‘#’ in front of the line that looks like: “tether 1 C:\hiball\config\hiball3xxx.cfg”.
- ❑ Start the server with autocalibration on and multi-model switching turned off (change the line in your tracker config file from ‘multimodel on’ to ‘multimodel off’), and the regular map file (one that was created by makemap or that was included in your installation files).
- ❑ Immediately after the server is started, walk the HiBall sensor around under the ceiling for several minutes (larger ceilings typically take longer than small ceilings).

Move the sensor slowly around so that it can 'see' all of the LEDs under the ceiling. (Moving the sensor up and down and rotating it will help see more LEDs quickly. You can use the installation camera to view LEDs while you do this to get an indication of which LEDs are being seen.) Monitor your progress by periodically clicking the 'update statistics' button on the Beacons tab and make sure that the number of beacons unseen goes to zero. Continue moving the sensor around under the ceiling until the 'beacon correction factor' goes to 0.3 or lower.

- ❑ When the correction factor is low enough, immediately click the 'write corrected map' button to write a new ceiling map file to the HiBall\config folder. The file will be named similarly to the ceiling map you started with. For example, if you started with the map file 'C:\HiBall\config\C18.map', the corrected map will be named 'C:\HiBall\config\C18.calib.h0.map'.
- ❑ Edit your tracker config file to turn multi-model switching and your second sensor (if applicable) back on.

Starting the tracker with a pre-calibrated ceiling map

To have the tracker start with the new map file you created, edit the *Tracker Configuration File* (described in Section 6.2.1). Change the "ceilingmap" line to point to the new ceiling map filename. This map will be loaded for each HiBall sensor. You can verify that it loads the proper file by looking at the 'Configuration' tab of the HiBall Control Panel (see Section 3.1.1).

6.4 Customizing Multimodel Switching

Multimodel Kalman filter switching allows the tracker to adapt to user motion. The tracker effectively changes the Kalman Filter 'process model' (or 'plant model'). When the user is moving quickly, the tracker uses a 'Position-Velocity' process model, which is based on the user being in motion. When the user is still or moving slowly, the tracker uses a 'Position' process model, which is based on the user being still. The tracker actually runs both filters in parallel and takes output from the one that is most appropriate at a given time.

Your HiBall system ships with default multimodel parameters that should work well with most applications. The following describes how to observe multimodel switching behavior or adjust the parameters. Multimodel information is presented on the 'Multimodel' tab of the HiBall Server Control Panel (see Figure 20).

Multimodel state information

The top of the display indicates whether multimodel switching is on or off. This is set in your Tracker configuration file by specifying 'multimodel on' or 'multimodel off'. See Section 6.2 for more details on the Tracker configuration file format.

Under 'state', the display indicates whether the system considers the HiBall sensor to be still or moving at the present time. While the state actually changes at the measurement rate (typically 1000 to 2000 Hz), the display in this control panel is updated slower. For testing purposes you may wish to increase the update rate for the control panel using the field near the bottom of the multimodel tab (enter a rate and click the Tab key).

Customizing the switching behavior

The tracker will switch state according to translational and rotational velocity thresholds. These parameters can be changed in this panel. The first number gives the velocity; the second number specifies a buffer to avoid hysteresis effects. If you wish to change the default parameters, you can edit these lines in your tracker configuration file. The appropriate lines are 'multimodelt <vel> <buffer>' and 'multimodelr <vel> <buffer>'.

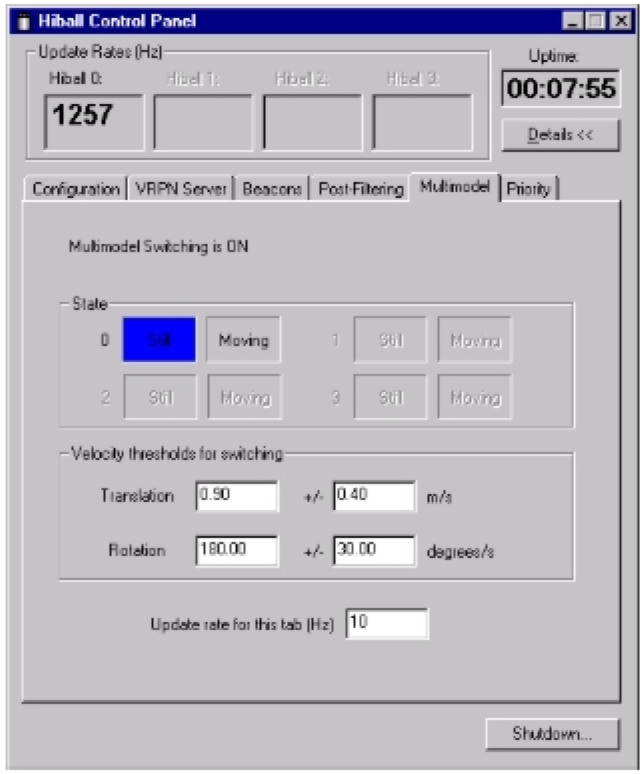

Figure 20. Multimodel tab in the HiBall Control Panel

6.5 Upgrading software

6.5.1 Updating Windows and Virus Software

Applying standard Microsoft service packs (e.g,, for security patches) to your Hiball PC's operating system should not cause problems. Similarly, updating the installed virus program software should also have no adverse effects on the system. However, changing to a different Windows version (e.g, from NT to XP) is not recommended, as it may require different drivers for the parallel port and different OS settings. If you need to do this, contact support@3rdtech.com for assistance.

6.5.2 Upgrading VRPN

You can retrieve an updated version of VRPN to use with your client software at any time from the VRPN web page

http://www.cs.unc.edu/Research/vrpn/.

Note that the major version number of VRPN must match the major version number of the HiBall server. When a new major version of VRPN is released, you'll be informed about a new release of HiBall software. (The current VRPN release is version 7.09. The next major release will be 8.0.)

6.5.3 Upgrading HiBall tracker software

HiBall software upgrades will be available on occasion from 3rdTech. You'll be contacted when new releases are available. Please report any problems or suggestions to support@3rdtech.com.