personal space

tracker

Instruction Manual

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Safety Notices

RSI warning: As with any human-computer interaction, please take frequent breaks, especially if you feel any unusual fatigue or discomfort, in order to prevent the possible occurrence repetitive strain injuries.

LED radiation warning: The tracking system inside the PSS uses infrared LED flashes to illuminate the tracked volume. These flashes are generated with a frequency of up to 55 Hz with a duration of 2 ms.

In general, light of high intensity might cause damage to the user's eyes. As infrared light is invisible for human beings, one might be exposed to a high intensity of light without knowledge. The American Conference of Government Industrial Hygienists (ACGIH) publish 'Threshold Limit Values' (TLV). According to the ACGIH, the TLV for the irradiance of near infrared radiation of viewing longer than 16 mins is 10 $mWcm^{-2}$. LED manufacturer OSRAM recommends the IEC 62471 standard ("Photobiological safety of lamps and lamp systems") to be taken into account, which follows the ACGIH TLV.

The maximum radiant intensity of the tracking system in the PSS stays well below the ACGIH TLV for viewing distances of over 10 cm from the tracking system. Nevertheless, PS-Tech recommends not to look directly into the tracking system, in particular at very close distances (< 10 cm). If harmful use of the PST is possible, all people in the room need to be instructed of the risk.

Contents

1 Item check list

Check that all the following items have been included with your Personal Space Tracker. If anything is missing, contact your dealer.

- Personal Space Tracker (PST)
- One interaction device
- One registration device[1]
- Power adapter
- Ethernet cable
- A starter set of 7 mm retro-reflective markers
- Personal Space Tracker Solutions Disk (CDROM)

[1] Only applicable to selected PST models

2 Safety precautions

2.1 Operating conditions

- Please use the Personal Space Tracker in AC grounded power sockets:
  AC 100-240 V, 1.6A, 50-60Hz
- Environmental conditions:
  +5° C ~ +35° C, 20% ~ 80% RH

2.2 Handling precautions

- The Personal Space Tracker is a precision instrument. Do not drop it or subject it to physical shock.
- The Personal Space Tracker is not water resistant and cannot be used underwater or be exposed to moisture.
- Do not use or store the Personal Space Tracker near heat sources such as ovens or direct sunlight. High temperatures can cause damage to the system or inaccurate measurements.
- Never attempt to open the tracker's casing, remove any of its components, or disassemble the tracker. Opening the tracker's casing can cause damage to the internal electronic circuitry and will void your warranty.
- Never use or store the camera near anything having a strong magnetic field or emitting strong radio waves, such as magnets or antennas. Strong magnetic fields can cause measurement errors or tracker malfunction.
- To reduce tracking inaccuracies, avoid using the Personal Space Tracker in a place that receives direct sunlight.
- If the Personal Space Tracker is not used for a long time, unplug it and store it in a cool, dry, well-ventilated location.
- Do not block the ventilation openings in the casing of the Personal Space Tracker. Blocking the openings may cause overheating.
- Do not scratch or otherwise damage the front window of the Personal Space Tracker. A scratched or damaged front window may cause measurement inaccuracies. Clean only with a very soft, perhaps lightly damp cloth.

3 Requirements

3.1 Software requirements

The Personal Space Tracker is a completely integrated solution, and as such does not require any external processing unit. The bundled software only communicates with the tracker and passes on its data, and therefore does not use much system resources. The software runs on the Microsoft® operating systems Windows XP®, Windows Vista®, Windows 7®, as well as on Linux systems with Glibc 2.3.2 and GTK+ 2.10 or greater and on Mac OS X version 10.4 or greater.

3.2 Hardware requirements

- Intel® Pentium® II 450MHz or faster processor (or equivalent)
- 128 MB of RAM
- One free RJ-45 fast Ethernet port (hub or network switch is also possible)
- An OpenGL capable graphics card

4 System description

4.1 Personal Space Tracker

The Personal Space Tracker (PST) is an optical tracking system that allows you to transform any object into a 3D interaction device. The PST is a complete tracking system and does not require the use of complicated calibration procedures or external processing units. It can be connected to your desktop computer or laptop directly, or through a network switch or hub. The PST brings 3D interaction to your computer without exhausting your own system's resources. A single PST is intended for optical tracking in small environments of up to 4 meters from the tracking system. Multiple PSTs can be coupled together to extend the workspace or reduce issues with line-of-sight. The PST is available with different optics configurations, such that the tracking area can be adapted. Optics with a higher field of view result in a wider tracking area closer to the PST, whereas a lower field of view gives a narrower but longer tracking area (see Figure 5.2).

The PST uses tangible, wireless interaction devices for 3D interaction. The position and orientation (pose) of the devices are reconstructed with millimeter accuracy. The system is based on infrared lighting, reducing interference of visible light sources from the environment. This allows the PST to be used under normal office working conditions, without requiring controlled lighting. Objects can be tracked by applying retro-reflective markers. The PST uses these markers to recognize different devices and to reconstruct their poses. Basically, any kind of physical object can be used as a device, e.g. a pen, a thimble, a cube, or even a toy car. Antenna like devices often used by other optical tracking systems can also be used.

The PST is available in two models:

- PST-55: Reconstructs the pose of interaction devices 55 times per second.
- PST-110: Reconstructs the pose of interaction devices 110 times per second. Due to the use of a larger imaging sensor, the field of view of these units is different.

4.2 Interaction Devices

Interaction devices are physical input devices that can be used to interact with virtual 3D objects in an application. Just as a mouse can be used to position a pointer in 2D, an interaction device is used to position an object in 3D with six degrees of freedom. The 3D position and orientation (pose) of an interaction device is optically tracked, ensuring wireless interaction.

4.3 Retro reflective markers

Retro-reflective markers are applied to objects to transform them into interaction devices. The tracking system uses these markers to recognize devices and to reconstruct each pose. In order for the Personal Space Tracker to be able to determine the pose of a device, at least four markers need to be applied.

The size of the markers determines the optimal tracking distance. For the near field Personal Space Tracker we recommend round markers or spheres with a minimum diameter of 7 mm.

4.4 Easy new device creation

New devices are easily created. Randomly add markers to a new device and use our software to train the system for that device. After the system has captured the device it can be used in your application. This process is described in Section 6.4.

5 Setting up the Personal Space Tracker

5.1 Mounting the Personal Space Tracker

To ensure optimal accuracy it is recommended to mount the Personal Space Tracker at a stable location. If the tracker can be moved somewhat, this movement is immediately shown as a movement in the tracked volume and therefore should be avoided. Furthermore, care should be taken that the PST has sufficient ventilation when it is mounted. Please make sure not to block the ventilation openings in the PST casings and allow for at least 20 cm of free, ventilated air around the PST casing.

The Personal Space Tracker can be mounted in two ways:

- Tripod mount: On the bottom of the PST a 1/4"-20 TPI mount hole is present. This allows the PST to be mounted on a standard tripod, see Figure 5.1. **Note that the tripod mount screw should not protrude more than 5 mm into the casing of the PST.** This is usually the case for standard tripod mounts. Otherwise damage to the PST might occur.
- Custom mounting[1]: On the bottom of the PST, four M4 mounting holes are present. These can be used to fasten the PST to other objects. **Note that the mounting screws should not protrude more than 5 mm into the casing of the PST**. Damage to the PST might occur otherwise.

Figure 5.1. The PST mounted on a tripod

[1] Only applicable to older versions of the PST

5.2 Positioning the Personal Space Tracker

The Personal Space Tracker has a certain field of view (FOV) in which devices are tracked optimally. The FOV and distance to the tracker depends on the choice of lenses and the model of the PST. Position the Personal Space Tracker such that it has a clear view of the volume that has to be tracked. Different versions of the PST-55 and the corresponding working volume are illustrated in Figure 5.2.

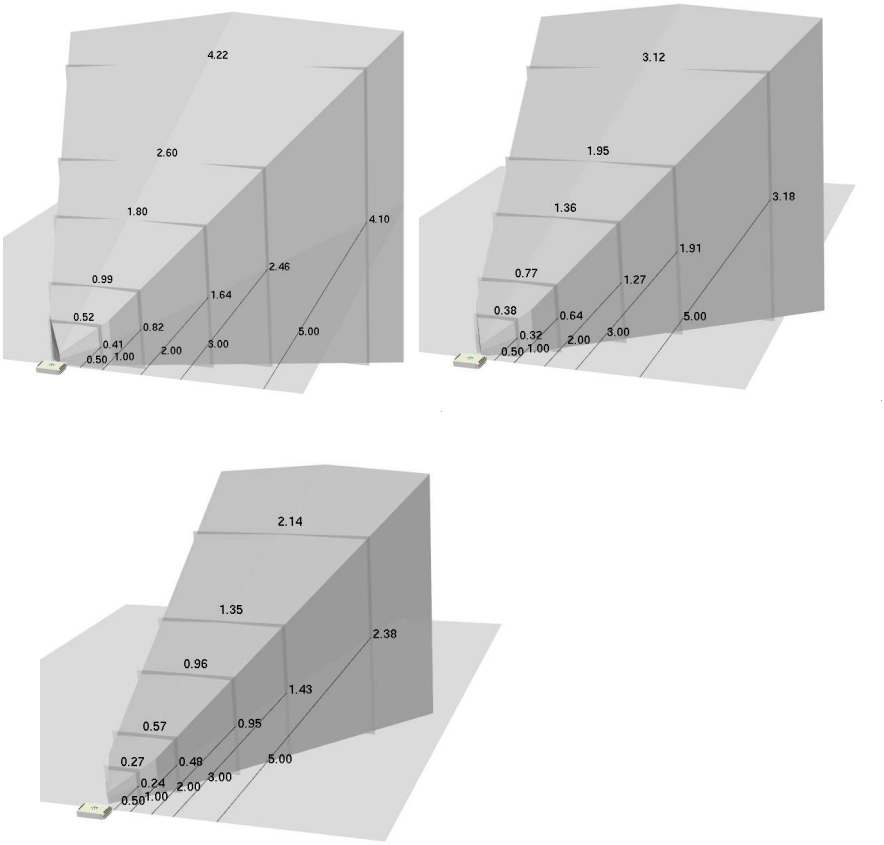


Figure 5.2. The PST tracking volume for different versions of the PST-55 (3.5mm, 4.5mm, and 6 mm lenses).

5.3 Reference coordinate system

The Personal Space Tracker reports the 3D position and orientation of each input device it finds in a metric, right-handed Cartesian reference coordinate system. The location and orientation of this coordinate system is pre-defined relative to the tracking unit. Figure 5.3 shows how the reference coordinate system is defined with respect to the Personal Space Tracker. The axes of the coordinate system are aligned with the tracker unit. If the PST is placed horizontally facing the user, the x-axis points to the right, the y-axis points up, and the z-axis points in the direction of the user. The origin of the coordinate system resides 40 cm in front of the PST unit.

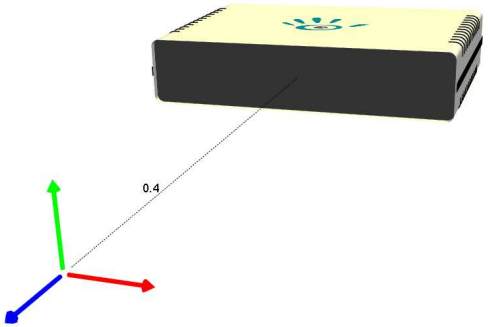


Figure 5.3. Default reference coordinate system

Many environments where 3D tracking systems are employed already have a coordinate system defined. In such cases, the Personal Space Tracker software provides for an easy mechanism to change its internal reference coordinate system. An interaction device can be used to set a new reference coordinate system. This process is described in Section 6.8.

5.4 System illustration

Figure 5.4 illustrates the front and back panel of the Personal Space Tracker. The panels consist of six parts:

A. *The front window*
   This window is used to block visible light passing to the cameras. Take care not to damage or scratch this window. Damaging this window may influence tracking performance.

B. *The status LED*
The status LED is used to notify the user of changes in the status of the PST. When the power is turned on, the LED turns orange. When the system is ready for tracking, the LED turns green. On system failure, the LED turns red.

C. *The ethernet connection jack*
This port is used to connect the PST to your computer or network.

D. *The system fan*
This opening is used for system ventilation. Please keep this opening clear of any obstructions.

E. *The on/off button*

F. *The power adapter connection*

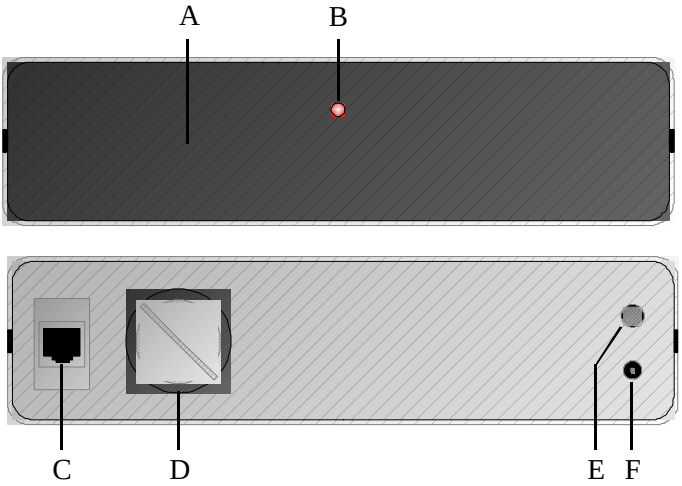


Figure 5.4. The PST front (top) and back (bottom) panel

5.5 Connecting the Personal Space Tracker to your computer

The Personal Space Tracker is connected to your computer using an Ethernet connection. The tracker can be connected in two ways:

- Using a network switch or hub
- Directly connecting it to your computer's network port

The Personal Space Tracker has two mechanisms for determining an IP address. The first one is used when a DHCP server is found to assign a dynamic IP address to the tracker. This address often has the form 192.168.x.x. In case the

tracker cannot obtain a dynamic IP address, a link-local address is defined with the form 169.254.x.x. In order for computer and Personal Space Tracker to be able to communicate, both should have an IP address of a similar form. This implies that if a link-local address is assigned to the Personal Space Tracker, the computer should also have a link-local address. Windows systems automatically obtain a link-local address in case no dynamic IP address can be determined. Most Linux systems do not automatically acquire a link-local IP address if necessary. This functionality can be added by installing third party software such as avahi-autoipd.

The PST client software provides an easy way to connect to the tracker without needing to know its IP address by using a network discovery technique. On startup, the client software sends a multi-cast DNS message identifying each connected Personal Space Tracker. The reply will contain the tracker's IP address and description. Trackers outside the local subnet cannot be used. For the network discovery to work properly, along with the PST software a system service is installed. On Windows systems, the service has the name “Bonjour Service”, whereas on Linux the service is named “mdnsd”. This service should not be removed or disabled.

The Personal Space Tracker uses internet protocol to connect to other devices. Before attempting to connect the Personal Space Tracker to your computer, please make sure that the following ports are forwarded in your firewall settings:

- TCP ports 27536 and 27537.
- UDP ports 5353 and 27538.

When a second tracking system is connected, the tracker uses the next ports, starting from 27539. For more information, check your firewall documentation.

Due to the real time communication between a user’s computer and the tracker, it is strongly recommended to limit the amount of routing and network communications. To limit network configuration issues and to minimize tracking latency, the PST and the client PC are used on a dedicated local network.

To connect the Personal Space Tracker to the computer, please follow the steps below. Refer to Figure 5.4 for the tracker connections.

Preparation: Switch of all components before starting connection.

1. Secure the Personal Space Tracker in a stable position by using for instance a tripod or wall mount.

2. Position the Personal Space Tracker such that it has a clear view of the volume that has to be tracked (see Section 5.2).

3. Connect one end of the RJ-45 Ethernet cable to a free Ethernet port in your computer or Ethernet switch. Connect the other end of the Ethernet cable to the Ethernet port in the Personal Space Tracker (Figure 5.4, **C**).

   Note: Use the proper Ethernet cable for connecting the PST to your computer.
   - A cross over Ethernet Cable is required when the PST is directly connected to your computer.
   - A conventional Ethernet cable is required when using a network switch or hub.

4. Plug in the power supply of the Personal Space Tracker (Figure 5.4, **F**).

5. Turn on the Personal Space Tracker by shortly pressing the on/off switch (Figure 5.4, **E**). Verify that the power light turns on (Figure 5.4, **B**). Next, verify that the ready light turns on properly. This process can take up to 30 seconds after pressing the power button.

6. Turn on the computer and insert the Personal Space Tracker Solutions Disk. Install the software following the instructions on the screen. Note that previously installed versions of the software should be closed before installation.

7. Run the Personal Space Tracker Software. See Chapter 6 for more details.

5.6 Turning off the Personal Space Tracker

If the Personal Space Tracker is not used for a longer time, it should be turned off. Shortly press the on/off button (Figure 5.4, **E**) to shut down the Personal Space Tracker. It takes a few seconds for the system to turn itself off and the power light to turn off (Figure 5.4, **B**). In case the Personal Space Tracker has entered an erroneous state and the system does not turn off, holding the power button for over 4 seconds turns off the system. However, this is not recommended for normal operation, as the system does not shutdown cleanly and this may result in data corruption of the PSTs internal memory.

6 Basic Operation

6.1 Establishing a connection to the Personal Space Tracker

Turn on the Personal Space Tracker and wait for the ready light to turn to green (see Section 5.4). Then start the Personal Space Tracker Software. The main window will appear, along with a connection dialog as shown in Figure 6.1.

The Personal Space Tracker Software automatically detects which Personal Space Trackers are connected. The connection dialog displays a list of Personal Space Trackers that have been discovered. Please note that enumerating the connected trackers may take a few seconds. Should your tracker not appear in the list, please check your firewall settings and all connections carefully and restart the software.

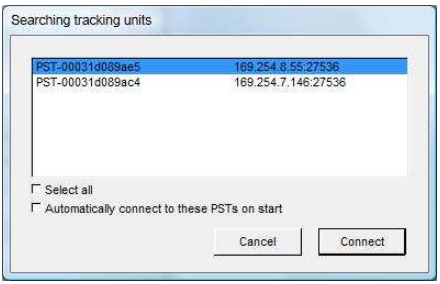


Figure 6.1. Connection dialog

Tracking units appear in the list with a name and an IP address. The name of a Personal Space Tracker always starts with “PST”, followed by 12 characters which represent the Media Access Control (MAC) address of the unit. Please note that although multiple Personal Space Tracker units can be present in the same network, a PST unit can only be connected to one single client program at a time. The client software can connect to multiple Personal Space Trackers.

If a tracker has been discovered, it appears in the list with its name and internet address. If more than one tracker is connected to a computer, the internet address can be used to distinguish between different trackers. Simply select the Personal Space Trackers you wish to connect to in the list and press “Connect”. Multiple selections can be made by dragging the mouse, by pressing “Select all” in the connection

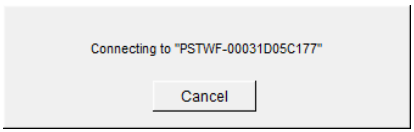


Figure 6.2. Connection in progress

dialog, or by using the Control key. The connection between the tracker and your computer will be established. During this process the dialog in Figure 6.2 appears.

If you receive an error message following a connection attempt, close the error message and check all connections, the firewall settings (see Section 5.5), and that the ready light of the Personal Space Tracker is on. Next, reconnect. If the problem persists, refer to Chapter 8 for troubleshooting suggestions.

Normally the connection dialog appears each time you start the PST client software. You may want to automatically connect to the same units. This can be accomplished by pressing the check-mark to automatically connect to the same units when starting the software. Note that for this to work, the Personal Space Trackers always should be switched on and ready before starting the software. In case the software cannot connect to the tracker for a certain time, the connection dialog reappears.

6.2 Camera images

After the connection is established, it is possible to view the camera images of the Personal Space Tracker. This enables a user to verify the correct operation of the tracker and to accurately setup the system to cover a certain working area. The camera images can be viewed by opening the “view” menu and pressing “camera images”. A window as shown in Figure 6.3 is opened.

Figure 6.3. Viewing of camera images

Note that the viewing of the camera images is intended only for setup and verification purposes. The transfer of the camera images uses most of the

available bandwidth in the network, and may interfere with the tracking itself. Therefore, in normal usage scenarios the camera image window should be closed.

6.3 Tracking

When the tracker is connected, the main window appears with the tracking page activated, as illustrated in Figure 6.4. The program opens on the tab page “Tracking options”.

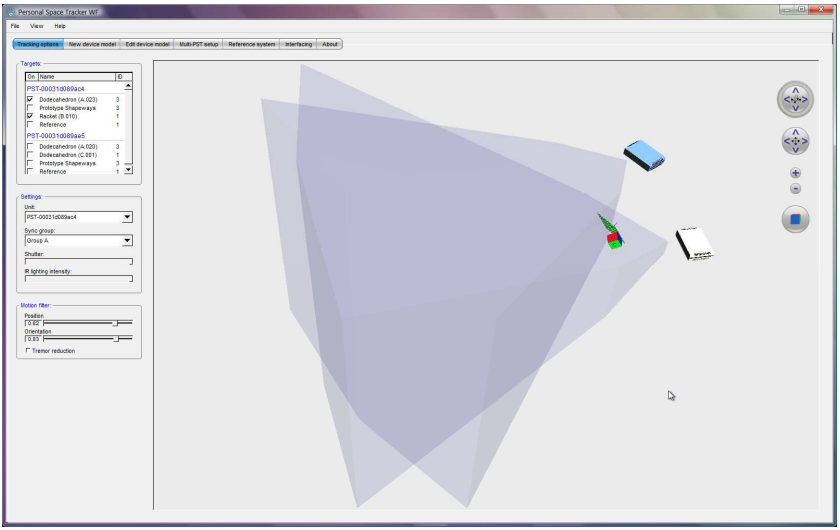


Figure 6.4. PST window in tracking mode

The main tracking window is divided into four parts: a device list, settings, viewing parameters, and a tracking live view.

Device list

The device list contains all interaction devices that are currently present in the model data base of the trackers, and subsequently can be tracked by the Personal Space Trackers (see Figure 6.5). The list includes the interaction device that is included in the package. If multiple trackers are connected, the devices of all units are listed.

The checkmarks in the list indicate whether the Personal Space Trackers are tracking the given interaction device. Only interaction devices with a check-mark are tracked by the Personal Space Trackers. Note that when multiple trackers are connected, all devices are shared. In case a device model is present in multiple trackers, only one of these should be selected. The user can change which devices are to be tracked by clicking the checkmarks in front of the device names in the list. The Personal Space Trackers are immediately updated when the list is changed.

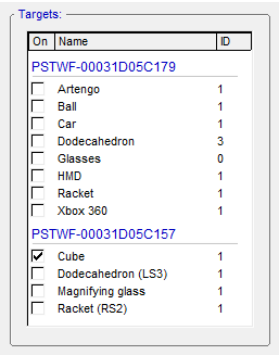


Figure 6.5. Device list

In the last column of the device list a device identifier (ID) is displayed. This ID can be used by external tracking interfaces that cannot handle device names. This includes interfaces such as VRPN and WorldViz Vizard. The ID of each device can be changed on the fly.

Settings

To change the settings of a unit (see Figure 6.6), first select the desired tracker by selecting it from the list of trackers or click on the tracker in the tracking live view. The following settings can be changed:

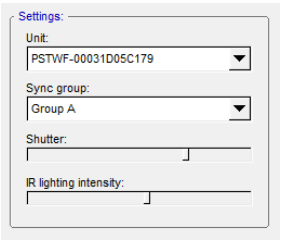


Figure 6.6. PST settings

- The synchronization group. Because multiple units that are facing each other may blind each other with their internet flash, units can be placed in different synchronization groups. If a tracker is placed in group A and a second tracker is placed in group B, the latter one takes its snapshot a few milliseconds after the other tracker.
- The shutter time. This sets the time the camera shutters are open to take a snapshot. A lower shutter time results in less motion blur and sensitivity to stray infrared light, but also in generally darker images and less visibility in the markers. This option can be used to tune the tracker to a particular environment.
- The IR lighting intensity. This set the illumination intensity and can be used to extend the range of the tracker. If devices appear overexposed, reduce the intensity. If markers are hardly visible, increase the intensity.

Motion filter

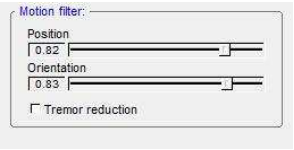


Figure 6.7. Motion filter

The PST is a measurement system with a certain precision. Small measurement inaccuracies may result in some visible jitter in the position and/or orientation of an input device. This effect gets stronger when moving further away from the PST. The pose of each reported device can be filtered using a motion filter. The strength of the position and orientation filtering can be adjusted by moving the slider, where 1 is maximum filtering and 0 is no filtering.

When using the PST as an interaction tracker, natural hand tremor can be filtered by checking the box for tremor reduction.

Tracking live view

The tracking live view (Figure 6.8) displays the 3D position and orientation of each of the interaction devices that are currently being tracked and identified by the Personal Space Trackers. The devices are represented by cubes or coordinate systems. The data is updated 55 times per second, which is the same as the update rate of the Personal Space Tracker.

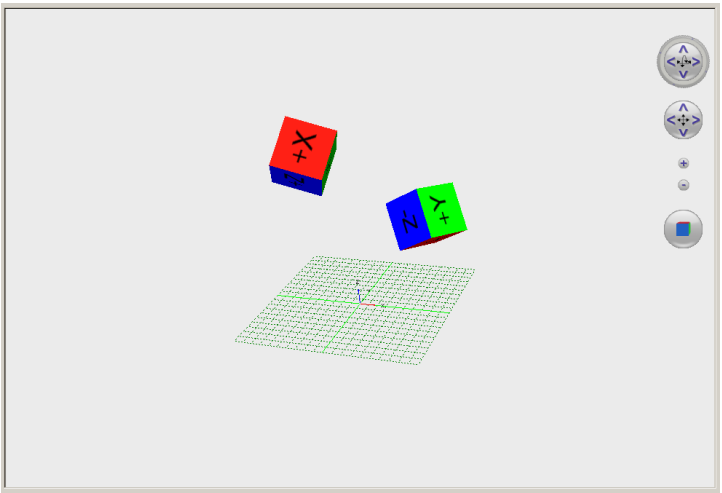


Figure 6.8 Tracking live view window

The tracking live view can be manipulated using the buttons on the right side of the window. Alternatively, it can be manipulated with the mouse:

- Left mouse button and drag left/right/up/down: rotate the view.
- Middle mouse buttons and drag left/right/up/down: translate the view.
- Right mouse button and drag up/down: zoom in/out.

Note that the tracking view serves only as feedback to the user to check if devices are tracked properly.

6.4 Training

Training refers to the process of "teaching" the Personal Space Tracker to recognize and use new objects as interaction devices. This is done by equipping an object with small circular markers and slowly moving the object in front of the Personal Space Tracker. During this object motion, the Personal Space Tracker internally constructs a model of the object, which is used to identify each interaction device. The training page is selected by pressing the "New device model" tab page in the main window (see Figure 6.9).

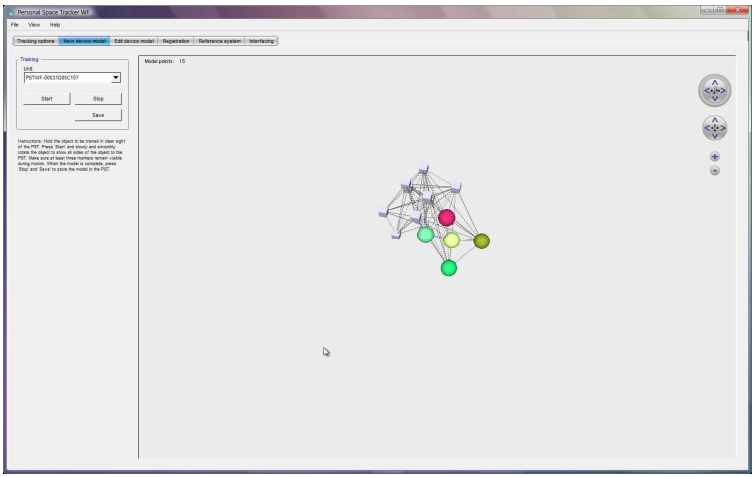


Figure 6.9. PST window in training mode

New devices can be trained as follows:

1. Attach four or more retro-reflective markers to the object. Refer to Section 6.5 for device construction guidelines. Place the object in the middle of the working volume of a Personal Space Tracker, in clear sight. Remove any other interaction devices and reflective materials

from the working volume. Having more than one object visible during training can cause incorrect device models. The training procedure can train single objects containing up to 100 markers.

2. Select the tracker to use for training and press the “Start” button in the training window. The training live view is updated and displays the 3D points corresponding to the visible markers. An example training session is shown in Figure 6.10. The colors encode the different markers in the device model. Grey cubes indicate that a previously visible marker is occluded and its position is being predicted by the Personal Space Tracker. The training live view can be manipulated in the same way as the tracking live view (see Section 6.3).

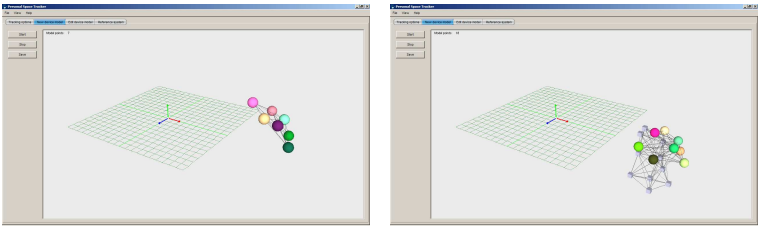


Figure 6.10. Training in progress

3. Slowly and smoothly move and rotate the object in front of the Personal Space Tracker such that all markers will be shown to the system. Make sure that three or more markers always remain visible during motion. In case not enough markers remain visible, training is aborted and the window as shown in Figure 6.11 appears. In this case, close the window and restart the training procedure. If the problem persists, check that the device has enough visible markers from each angle.

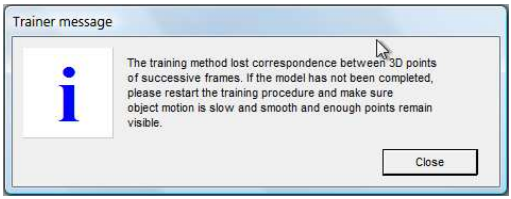


Figure 6.11. Correspondence lost

When the displayed number of interaction device markers reaches the actual number of markers on the object, press the “Stop” button. The training live view can now be used to view the device model as obtained by the Personal Space Tracker.

An example input device with the corresponding device model as obtained from the training procedure is illustrated in Figure 6.12.

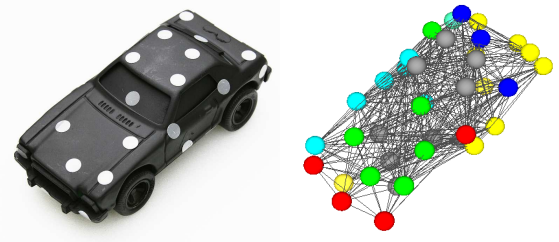


Figure 6.12. Example of an object with the trained model

4. If the device model is finished and the new interaction device is to be used in practice, press the "Save" button in order to store the model. A dialog as given in Figure 6.13 appears asking you to enter a model name and ID. Please enter a unique name, select a device ID, and press "Save".

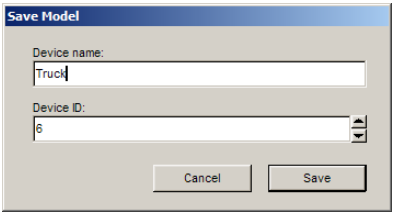


Figure 6.13. Saving a device model

5. Return to the tracking view and select the new interaction device. The device should immediately be visible in the tracking live view.

6. If necessary, the relation between the device model and its coordinate frame can be adjusted. See Section 6.6.

6.5 Device construction

New devices are easily constructed by applying a number of markers randomly onto the object. However, some care should be taken to ensure optimal performance of a device:

- For the tracker to identify and track an object, it should always have a clear sight of at least four markers on the object. So, make sure that for each viewing angle on an object at least four markers are visible.

- The pattern of the markers on the device should be more or less random. In order to avoid ambiguities try to make sure no symmetric, regular, or similar patterns exist on the object.
- Note that co-linear markers (markers on the same line) do not provide sufficient information for the tracker to determine a full pose of the object.
- Use circular or spherical markers only, as these provide the most accurate and consistent positional accuracy.
- Use markers with a minimum diameter of 7 mm. Larger markers may provide better accuracy, whereas smaller markers do not provide sufficient information for accurate tracking.
- The minimum marker distance should be approximately 5 mm.

6.6 Model editing

The device models present in the device list can be edited. The model editing page allows the user to alter properties of a model, such as its name and reference coordinate system location and orientation. The model editing page is selected by pressing the “Edit device model” tab page in the main window (see Figure 6.14). The model editing view consists of two parts.

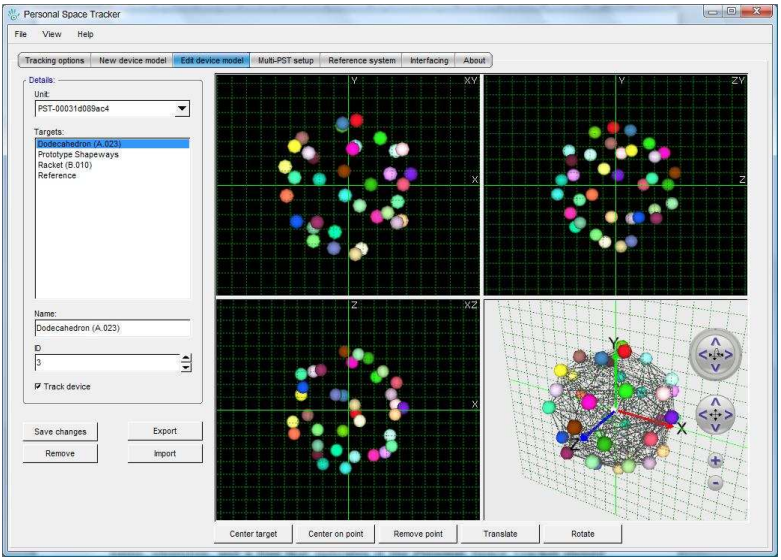


Figure 6.14. PST window in model editing mode

On the left side of the model editing page is a group of controls to select the tracking unit for model editing, an interaction device to edit, along with its name, identifier, and a flag that indicates if the Personal Space Tracker should track the device. Any changes to these parameters are not applied directly, but need to be committed to the memory of the Personal Space Tracker by pressing "Save changes".

An interaction device can be erased from the Personal Space Tracker by pressing "Remove". Please take care using this function, as the removal of interaction device models from the Personal Space Tracker is permanent: once removed, a device will have to be retrained (as described in the previous sections) before it can be tracked again.

Device models can be imported from and exported to a user's computer with the buttons "Import" and "Export". This feature is useful for backup purposes or for distributing existing device models to other tracking units.
On the right of the model editing view, the interaction device model is illustrated from different angles. The views subsequently show the projection of the device model onto the XY-plane, the ZY-plane, and the XZ-plane, as well as a full 3D view similar to the one in the tracking and training live view. The device model projections can be used to precisely orient and translate the device model with respect to the coordinate system that will be reported by the tracking system for this device. This is for instance needed in case a pointing device is created where the position reported by the Personal Space Tracker should correspond to the tip of the pointer and the orientation should be aligned to the Z-axis. The grid drawn in the device model projections has a spacing of one centimeter.

The projection views of the device model can be operated as follows:

- Left mouse button and drag left/right/up/down: change the orientation of the device model.
- Middle mouse button and drag left/right/up/down: change the position of the device model.
- Right mouse button and drag up/down: zoom in/out.
- Ctrl+left mouse button and drag left/right/up/down: position the origin.

On the bottom of the model editing page is a collection of buttons to manipulate device models. This includes centering the model, centering the model on the selected model point, and translating and rotating the model. Model points can be selected by pressing the left mouse button on a point in one of the projection views.

6.7 Multi-tracker setup

Multiple Personal Space Trackers may be connected and can work together in the same environment. This may serve two purposes:

- Reduce problems with occlusion, i.e. the line-of-sight requirement inherent in optical tracking. In case a device is regularly not visible for a tracker, adding a second tracker from a different viewing position may improve the issue.
- Extend the tracking volume. Multiple tracking units can be placed such that they view different parts of an area.

PST placement

Trackers should be placed such that each unit has an overlapping area with at least one other tracker. If the goal is to extend the tracking volume, the most efficient setup is to create a minimal overlap between PSTs, such that each unit adds a maximum amount of tracked volume. The overlapping area only serves as a means to be able to determine the position and orientation of multiple PSTs with respect to each other.

An example setup is illustrated in Figure 6.15. Here, four PSTs are setup such that the angle of the overlapping area between units is about 10 degrees.

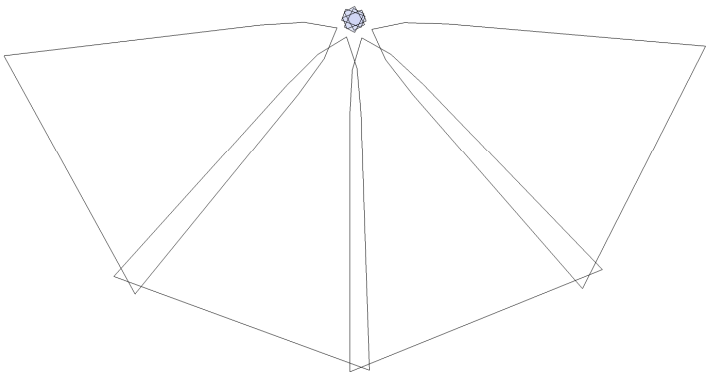


Figure 6.15. Possible setup of 4 PSTs where the tracking area is maximized.

Synchronization

The tracking data of connected PSTs is reported as if connected to a single unit. The position and orientation of each device that is enabled at the tracking settings page is determined based on the tracking results of each PST. As such, when a device is visible to either a single tracker or to multiple trackers, only a single device pose is reported each time frame. Note that enabling a device in one PST results in it being recognized by all connected units.

The trackers use a clock synchronization method running over the Ethernet connection. The synchronization method uses broadcasting UDP messages from the client PC to the PSTs. The synchronization status can be checked at the Multi-PST setup page. In some configurations (for instance if the netmask is incorrectly configured), the default selected broadcast address may not work, resulting in a “network error” message at the synchronization status. In this case, press “Settings” and select or type a different broadcast address, or check the networking configuration to make sure broadcast messages are not blocked. Note that routers often block broadcasts. To limit network configuration issues and to minimize tracking latency, it is recommended to use the PST on a dedicated, local network only.

Registration

To ensure that each tracker reports its data in a common coordinate system, a registration procedure is required. During this procedure, the position and orientation of all tracking units are related to each other.

The registration procedure proceeds as follows:

- Make sure all tracking units are placed in the same synchronization group during registration.
- Check that the synchronization status is “OK”.
- Press the “Registration” tab page in the main window to show the registration page.
- Press the record button and slowly wave the registration device through the working volume. Concentrate on the areas where tracking units have an overlapping field of view. Make sure that the device is clearly visible to the trackers and that motion is slow and smooth. During recording, the data is plotted as trajectories in different colors representing each tracker.

- When enough data has been collected, press the record button again to stop recording data. The registration window shows the recorded data points and the field of view of the tracking units. Note that at this time, the position and orientation of the trackers may still be incorrect. Check that all tracking systems have a set of 3D points, drawn in a different color for each tracker (see Figure 6.16).

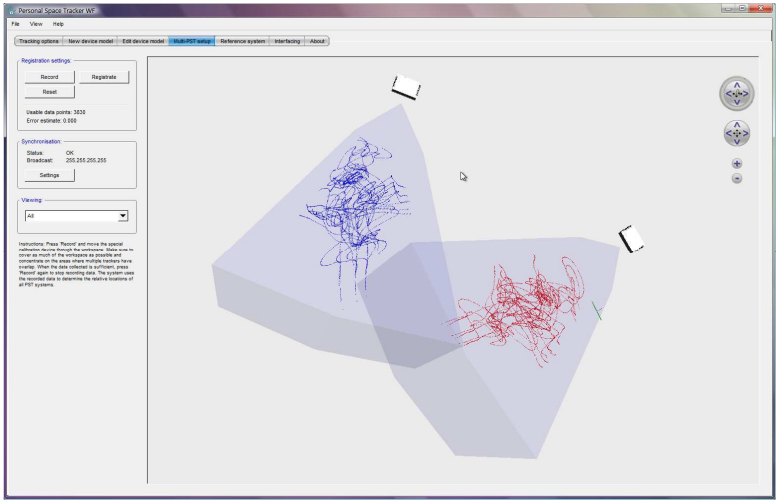


Figure 6.16. PST window in registration mode

- Press the “Registrate” button to execute the registration procedure. This can take from a few seconds to a couple of minutes, depending on the size of the data. Upon completion, the registration results are shown in the live view. The recorded point trajectories should be placed over each other (as illustrated in Figure 6.17), where the error estimate indicates the quality of the registration. A number below 0.5 is generally a good value.

In case a PST is not tracking objects well after registration, or if the recorded point trajectories are not neatly placed over each other, the factory default calibration of each PST can be restored by pressing “Reset”.

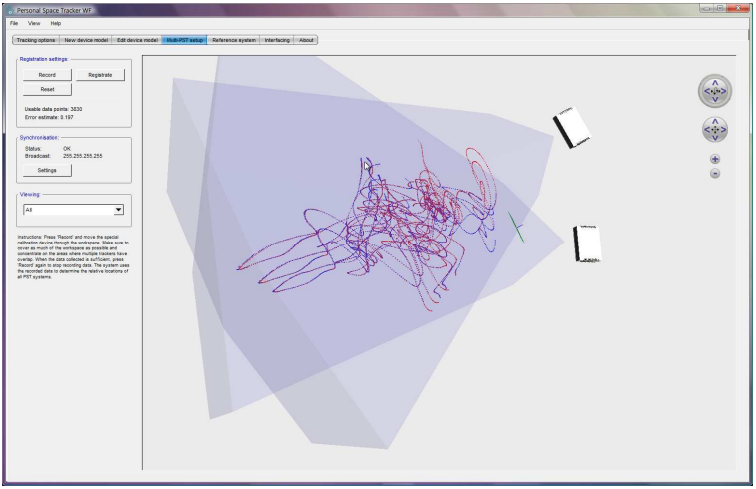


Figure 6.17. Registration results

6.8 Reference coordinate system editing

The reference coordinate system of the Personal Space Tracker can be adjusted to the user's likings. Press the “Reference system” tab page in the main window to reveal the reference system editing page (see Figure 6.18).

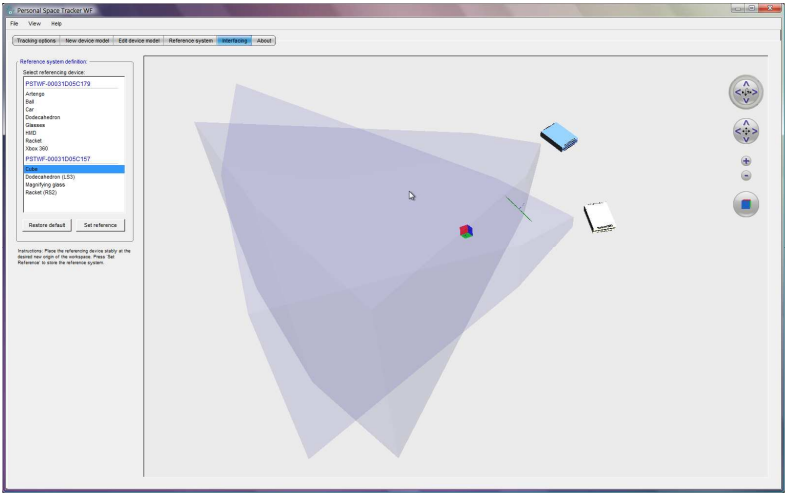


Figure 6.18. PST window in reference system editing mode

The reference coordinate system is defined relative to the PST systems. All reported tracking values from a tracker are with respect to the reference coordinate system (see Section 5.3). When integrating one or more Personal Space Trackers into an existing environment, the reference coordinate system can be aligned to the coordinate system already defined by the environment.

To set a new reference coordinate system, first select the device that will be used to define the new coordinate system. The selected device is shown in the live view as a Cartesian coordinate system. The x, y, and z-axes are encoded as follows:

- Red: x-axis
- Green: y-axis
- Blue: z-axis

The live view also shows a grid with the current reference coordinate system. The next step is to bring the device to the desired location within the tracking volume and align the displayed axes with the coordinate system used in the application. Once the coordinate system defined by the device and the coordinate system of the application are aligned, press “set” to update the connected Personal Space Trackers. The live view is immediately updated to reflect the new reference coordinate system. To restore the factory default reference coordinate system, press the restore default button.

7 Communicating with other systems

The Personal Space Tracker uses a proprietary interface to communicate its tracking data to the computer over the network. An application that needs the tracking data can communicate with the client tracking software using different interfacing options. These options are selected in the interfacing tab page as illustrated in Figure 7.1.

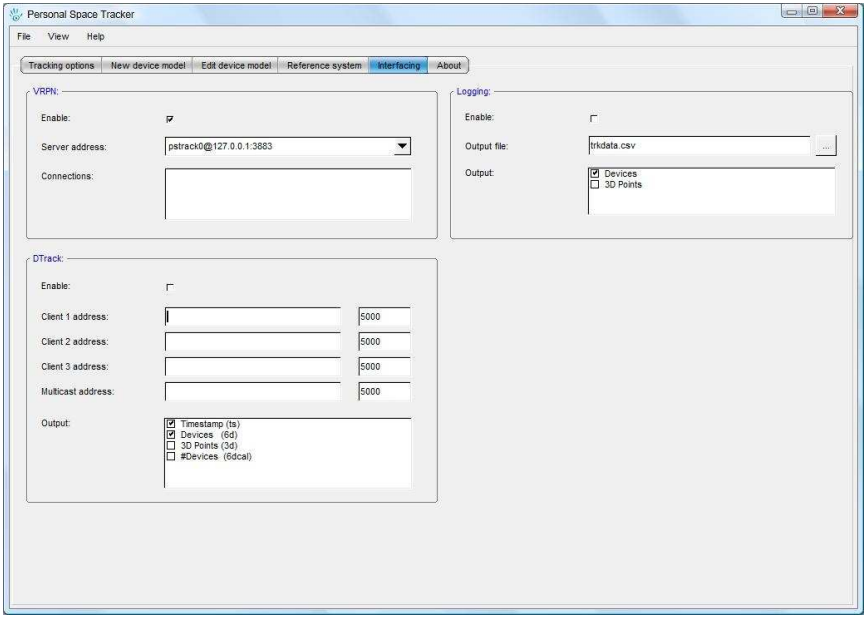


Figure 7.1. Interfacing options.

7.1 SDK

The Software Development Kit (SDK). The SDK and its documentation is located on the installation CD-ROM and allows for applications to directly communicate to the PST Client software.

7.2 VRPN

The Virtual-Reality Peripheral Network (VRPN) is a set of classes within a library and a set of servers that are designed to implement a network-transparent interface between application programs and the set of physical devices. The VRPN interface can be activated by checking the “Enable” box. The VRPN server address is given in the box below. If the computer has multiple active network interfaces, the interface on which the VRPN server should run can be selected here. The “Connections” list shows the currently connected VRPN clients. Note that the VRPN server runs on port 3883. When using multiple servers for other devices, make sure to configure other servers to run at a different port. Devices are identified in VRPN using the device IDs as specified in the tracking device list. For more information on VRPN, see http://www.cs.unc.edu/Research/vrpn/.

7.3 DTrack emulation

The DTrack emulation interface is a communication layer that enables users of A.R.T. tracking systems to interchange their old tracking systems with the PST. The DTrack emulation interface can send tracking data to one or more clients. Up to three different client IP addresses and port numbers can be specified. Alternatively, a multicast address may be specified to send data to multiple clients simultaneously. After specifying the client addresses, DTrack emulation can be activated by pressing “Enable”.

The DTrack emulation interface sends an UDP packet for each frame. A packet contain several ASCII string separated by CR/LF. Each line starts with an identifier, which specifies the type of data:

- fr <integer>
  The frame counter.
- Identifier ts <double>
  The timestamp, i.e. the time when the infrared flash of the cameras is fired. The timestamp uses the PC clock, given in seconds since the Epoch.
- 6d <tracking data>
  Measurement data of all tracked interaction devices. The tracking data starts with an integer specifying the number of devices, followed by a list of device measurements defined by

  $$[\text{id qu}][p_x\ p_y\ p_z\ \alpha\ \beta\ \gamma][u_x\ u_y\ u_z\ v_x\ v_y\ v_z\ w_x\ w_y\ w_z]$$

  where

- id: Device identifier, corresponding with the selected ID in the tracking device list.
- qu: Quality value (unused).
- p_i: Device position (meters).
- α, β, γ: Orientation of the device defined by Euler angles (degrees).
- u_i, v_i, w_i: The basis vectors of the rotation matrix.

- 3d <marker data>
  Measurement data of all tracked additional markers, i.e. markers not part of an interaction device. The marker data starts with an integer specifying the number of markers, followed by a marker list defined by
  [id qu][p_x p_y p_z]
  Containing
  - id: Marker identifier.
  - qu: Quality value (qu, unused).
  - p_i: Marker position (meters).
- 6dcal <integer>
  The number of tracked devices.

7.4 Data logging

The PST client software features logging functionality that enables a user to log tracking data to .CSV (Comma Separated Values) file. These files can be conveniently loaded into Microsoft Excel for data analysis. Specify an output file and press “Enable” to start logging tracking data to the specified file. Data logging can be stopped by unchecking “Enable” again.

Each line in the data file contains tracking data of a single time frame. A line contains the following data, separated by commas:

- The frame counter (integer)
- The timestamp (double), i.e. the time when the infrared flash of the cameras is fired. The timestamp uses the PC clock, given in seconds since the Epoch.
- The number of devices found (integer)
- For each device found, the following data is reported:
  name p_x p_y p_z α β γ
  Where
  - name: An ASCII string containing the device name.
  - p_i: The position of the device (meters).
  - α, β, γ: Rotation of the device defined by Euler angles (degrees).

- The number of marker positions (integer)
- For each marker found, the following data is reported:

  id p_x p_y p_z

  Where
  - id: Marker identifier.
  - p_i: Marker position (meters).

8 Troubleshooting

1. *Unable to turn on the PST.*
   Possible cause: the power is not connected properly
   Remedy: connect the power adapter included with the PST to the power input of the PST unit and a suitable wall socket.

2. *The ready light does not turn on.*
   Possible cause: The ethernet cable is not connected properly.
   Remedy: Please check that the ethernet cable is connected properly. Take care to use an appropriate type of cable: connecting the PST directly to the computer requires the use of a cross-over ethernet cable, whereas connecting it through a switch would require the use of a normal ethernet cable.

3. *No tracking units found.*
   Possible cause: No tracking units connected on the same local network as the computer.
   Remedy: Connect the tracking unit directly to the computer or on the same local network.
   Possible cause: Disabled system services.
   Remedy: Make sure the network service discovery services are enabled and running. On Windows, this can be done by running services.msc and checking the Bonjour service is enabled and running. On Linux, check that the service mdnsd is active.
   Possible cause: A firewall blocks network service discovery.
   Remedy: Check the firewall settings and unblock UDP port 5353 for the Personal Space Tracker software.

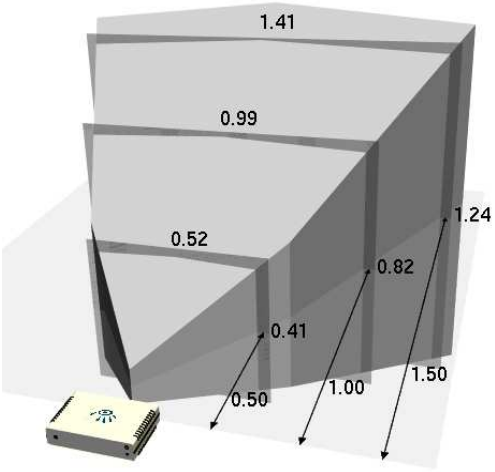
4. *Unable to connect to a unit.*
   Possible cause: A firewall blocks tracker communications.
   Remedy: Check the firewall settings and unblock TCP ports 27536 and 27537 and UDP ports 5353 and 27538 for the Personal Space Tracker software.

5. *Performance is slow, stuttering.*
   Possible cause: Too much other communication on the same network
   Remedy: Limit the other network communications or use the Personal Space Tracker on a dedicated network only.

6. *Connection error: Cannot connect to tracker*
   Possible cause: Ethernet cable was disconnected while Personal Space Tracker application was still running on the computer.
   Remedy: Close Personal Space Tracker application and Tracking unit and restart both.

7. *Devices move erratically*
   Possible cause: Disruptive elements present in the tracked workspace.
   Remedy: Make sure the view of the tracking system on the workspace is not disturbed by any objects or disruptive (reflective) materials or light sources.
   Possible cause: Damaged interaction devices or markers
   Remedy: Check that all markers on the interaction device and the device itself are in tact. Damaged or dirty markers may show degraded reflective performance.

9 Technical Specifications[1]

technical data	
refresh rate	55Hz
degrees of freedom (DOF)	6 (position and orientation)
# of targets (55fps)	at least 15 independent 6DOF bodies
working distance	at least 0.4 – 7m, depending marker size and tracker configuration
lighting	built-in IR flash
ambient conditions	normal indoor lighting conditions
field of view (FOV)	horizontal: 57 deg vertical: 44 deg  Other configurations available.
precision[2]	< 1 mm
	< 1 deg
calibration	pre-calibrated unit
6DOF target creation	easy training of custom built targets

1 Preliminary. Specifications are subject to change without notice.

2 precision measured using 7mm markers at a distance of 60 cm

interface	ethernet
output	x, y, z positional coordinates and orientation angles, rotation matrix or quaternions
power supply	12V, approx. 100W (external power supply 100–240V, 50–60Hz)
power consumption	max. 100 W
size	17.5cm(d) x 5.5cm(h) x 25.0cm(w)
weight	approx. 2 kg
processing unit	internal
minimum latency	approx 18 ms
software support	standard interfacing toVRPN, SSD, and most VR programs. Further extendible via simple SDK.