Fiducial Constellation Setup Guide

For Thales Visionix Fiducial Tracking Systems

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1. Understanding Purpose of Constellation of Fiducials

When you first receive a Thales Visionix optical inertial sensor, you may receive a kit containing fiducial stickers that look similar to the one shown below and a sheet of them you can print out yourself if you are using a visible light sensor. You place these fiducials in your environment; for instance, in the cockpit of your aircraft or in a room where the virtual or augmented reality action should occur. The tracker detects these fiducials and decodes the geometry to determine each one's unique ID. The tracker uses the location of the fiducial to orient and position itself in the environment.

Figure 1 Fiducial Sticker

You can set up a series of these fiducials in key locations in your environment. Figure 2 shows some sample fiducials from the **8.5x11 Fid Poster.pdf** file in the **documents** directory of the installation. The layout of fiducials in your environment is called the *constellation*.

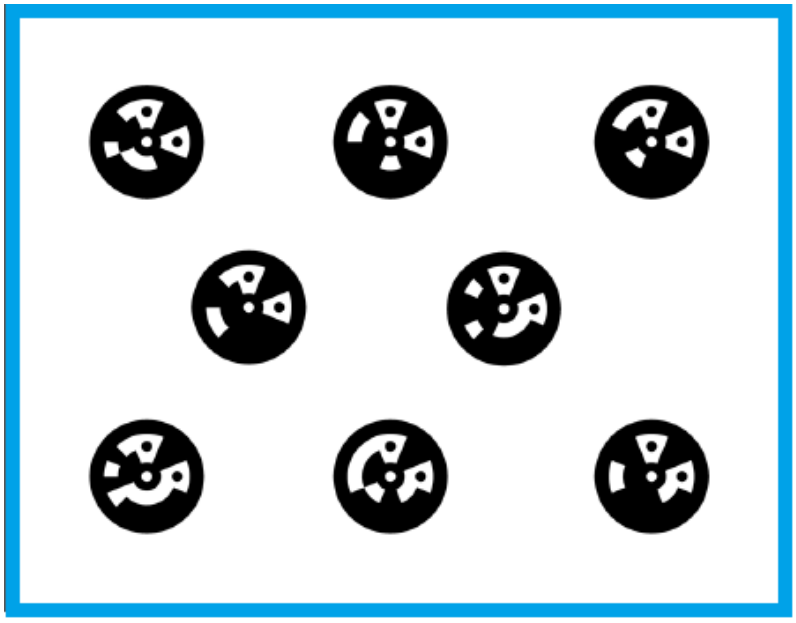


Figure 2 Multiple Fiducials on Sheet Provided

Each fiducial you add to your constellation has a unique identifier built into it—no two in the same constellation can have the same identification number. Each particular fiducial always retains the same unique identifier, totally independent of position or other information. To prevent duplicate fiducials, be sure the identifiers on each sheet you use are unique.

Each fiducial has three tracked points, each with a unique number. For fiducial 100, for example, the center (white) circle would be 100, while the secondary (black) circles inside the fiducial would be 101 and 102.

1.1 Types of Fiducials Available

Sample fiducials provided for Visual Light optical inertial sensors are paper. You can print additional fiducials of various sizes if you have the available software.

Fiducials provided for Infrared optical inertial sensors are made from retroreflective material.

The retroreflective fiducials are available in multiple diameter sizes. Part numbers for the various size retroreflective fiducials are shown in the table below.

Table 1 Part Numbers for Available Retroreflective Fiducials

Fiducial Part Number	Diameter
V14015-16-01	6 mm
V14015-16-02	8 mm
V14015-16-03	10 mm
V14015-16-04	12 mm
V14015-16-05	15 mm
V14015-16-06	19 mm
V14015-16-07	25 mm
V14015-16-08	35 mm
V14015-16-09	76 mm
V14015-16-10	127 mm

2. Determining Best Distance of Fiducials from Tracking Device

To determine the distance to place fiducials from the optical inertial sensor, you start by first knowing the focal length of the particular optical inertial sensor model you are working with. Your optical inertial sensor has one of these possible focal lengths:

- From 3 in to 9 in
- From 7 in to 25 in
- From 20 in to infinity (IS-1500 InertiaCam devices all have this focal length)

It is important to determine the maximum distance you want the optical inertial sensor to see fiducials from and ideal size fiducial that makes sense at that distance.

The rule of thumb is that the maximum distance of the optical inertial sensor from a fiducial should be about 20 times the size of the fiducial. Based on the *20 times the size* guideline, if your optical inertial sensor has a 7- to 25-inch focus, you could use fiducials between 10 mm and 35 mm. You can determine this size range yourself. The smallest fiducial at 7 inches away calculates this way:

7 in ÷ 20 = .35 in or 8.89 mm

(the nearest size fiducial that is not smaller than 8.80 mm is 10 mm)

And the smallest fiducial at 25 inches away calculates this way:

25 in ÷ 20 = 1.25 in or 31.75 mm

(the nearest size fiducial that is not smaller than 31.75 mm is 35 mm)

Note that these pre-determined sizes apply only to retroreflective fiducials; you can choose the size to print if you are using paper fiducials.

If a fiducial is too large, it will take up most of the optical inertial sensor's field of view. When a fiducial is about one quarter of the tracker's field of view, the optical inertial sensor can no longer detect the fiducial. Ideally, the optical inertial sensor should be able to see six fiducials at once in its 130° field of view.

The exact sizing depends on the environment and the typical usage distance.

Appropriate fiducial sizes at the different focal lengths would be roughly as shown in the table on the following page.

Table 2 Recommended Retroreflective Fiducial Sizes for Various Tracker Focal Length Ranges

Focal Length	**3 in to 9 in**	**7 in to 25 in**	**20 in & Up**
Fiducial Part Number	Diameter	Diameter	Diameter
V14015-16-01	6 mm		
V14015-16-02	8 mm		
V14015-16-03	10 mm	10 mm	
V14015-16-04	12 mm	12 mm	
V14015-16-05	15 mm	15 mm	
V14015-16-06		19 mm	
V14015-16-07		25 mm	
V14015-16-08		35 mm	35 mm
V14015-16-09			76 mm
V14015-16-10			127 mm

3. Designing Layout of Constellation

When you design a constellation, you need to adhere to general guidelines during positioning of the fiducials and take several steps to create the constellation itself.

3.1 Choosing a Surface for Your Constellation

When choosing a surface for locating your constellation, follow these guidelines:

- Ensure the surface is smooth to avoid distorting the fiducial's shape. You can use a curved or uneven surface as long as you position the fiducial carefully to avoid distorting its shape.
- Choose a rigid material that does not warp or sag over time.
- Although surface materials can be clear or opaque, opaque material is preferred for visible light to achieve the required annular ring.
- Select a surface that enhances the fiducial image. Non reflective/matte finish surfaces are generally best, but a surface that is slightly glossy still allow accurate mapping. Surface finishes in order of preference are: Matte, Semi-gloss, Glossy.
- Do not place fiducials on a mirror.
- Any supporting stand for your fiducial substrate should be strong and rigid. It should not allow the constellation to move or bounce when the user moves.
- Design portable stands so that they can return to the original mapped position. For instance, attach a spirit level to the constellation substrate to ensure that it is level in both pitch and roll before mapping and remains level over time, even when moved to a different location.

3.2 Guidelines for Positioning Fiducials

When you position a fiducial, follow these guidelines:

- Secure the position of each fiducial, so that it cannot move. Later, you use a tool called the Simplified Visual Mapper inside SFStudio software to create a map of how the tracker *sees* the fiducials in the environment. If the fiducial moves after you've created the constellation map, the map becomes less optimal or even invalid, depending on the severity. Sub-optimal maps can cause poor tracking performance and may cause jumps in interpreting the position and orientation of the tracker at random times.
- Be sure to keep a minimum annular ring between any two fiducials of at least the radius of the larger of the two fiducials. This distance provides a clear area to ensure the proper decoding of the fiducial.
- Use a mix of fiducial sizes on the same surface. The smaller fiducials become effective (visible to the optical inertial sensor) as the subject gets closer to the surface and the larger fiducials as the subject moves further away.

- Use a dense array of small fiducials to cover closer viewing ranges and in between them use a sparser array of larger fiducials to cover the more distant viewing range.
- When determining how dense the fiducial coverage of the area should be, the constellation should have a minimum of six fiducials in the 130° field of view that the optical inertial sensor can span. More fiducials allow for better tracking accuracy. The contribution to tracking accuracy from additional fiducials becomes far less dramatic after 12 to 15 are seen well spread throughout the field-of-view.
- Bear in mind the largest ratio of the farthest to closest acquisition distances (referred to as dynamic range) is a constant for the lens. It is the ratio between the far distance at which a fiducial in the corner becomes too small to read, and the close distance at which the same fiducial size in the center becomes too large to read.
- Avoid placing fiducials in a grid pattern. Instead, distribute your fiducials in a roughly circular or oval shaped area.
- Avoid having a single fiducial isolated from the others at the edge of the constellation.

Below is an example of a constellation of fiducials distributed in an oval shaped area:

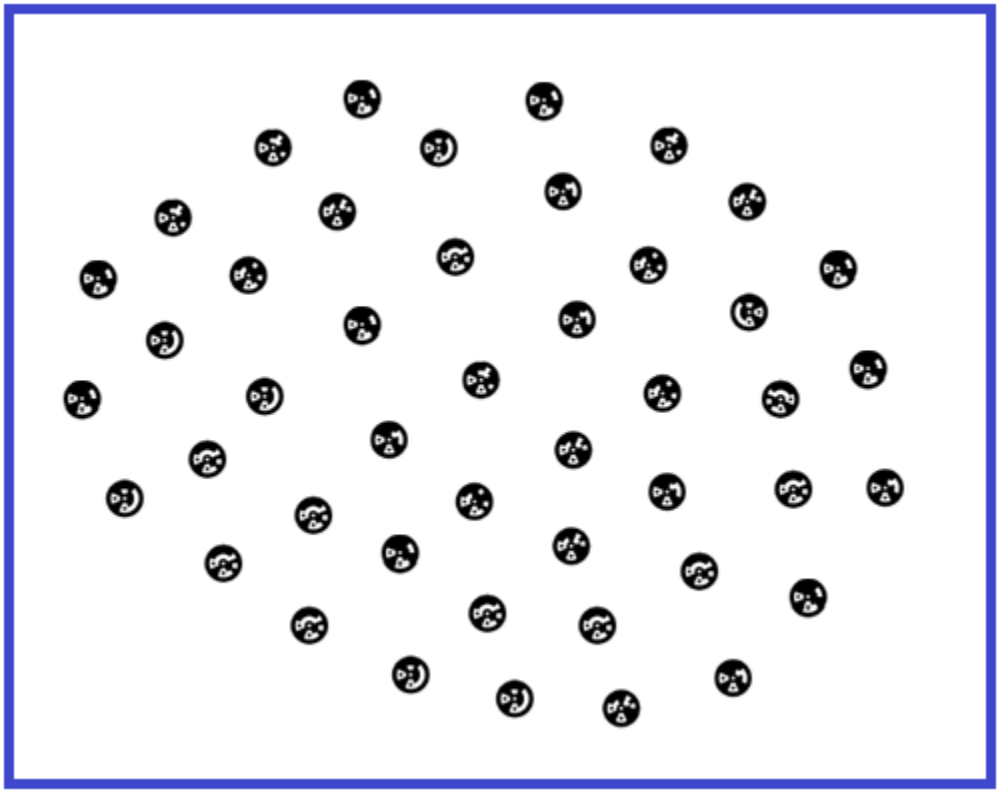


Figure 3 Fiducials Layed Out in an Oval Shape

The next illustration shows two constellations of fiducials, one with an isolated fiducial that would be problematic. The better constellation is shown to the right.

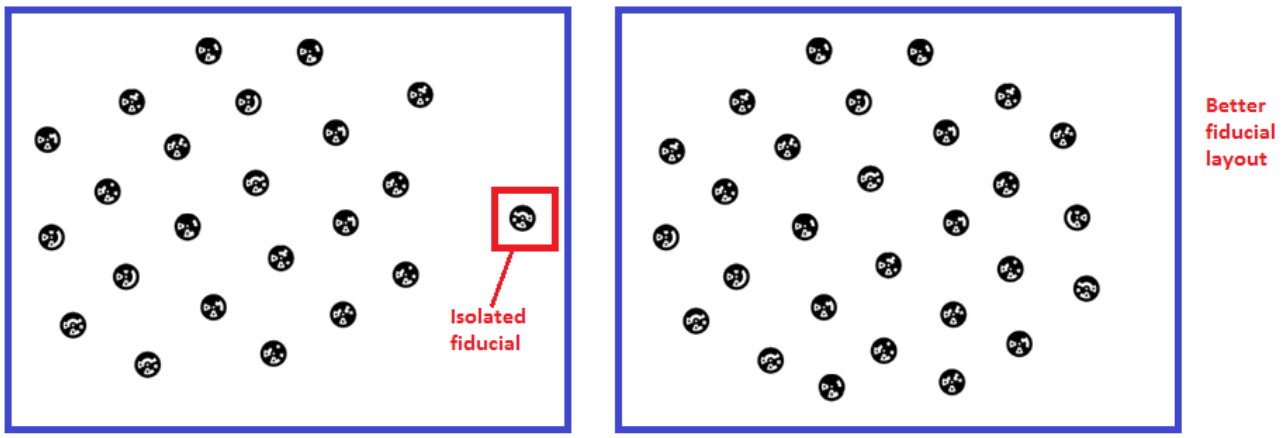


Figure 4 Constellation to Left Shows Isolated Fiducial, a Situation to Avoid

The figure below shows a sample constellation that has more than one size fiducial covering a wall. Notice that the smaller fiducials are in a more densely packed layout and the larger fiducials are interspersed in a sparser layout.

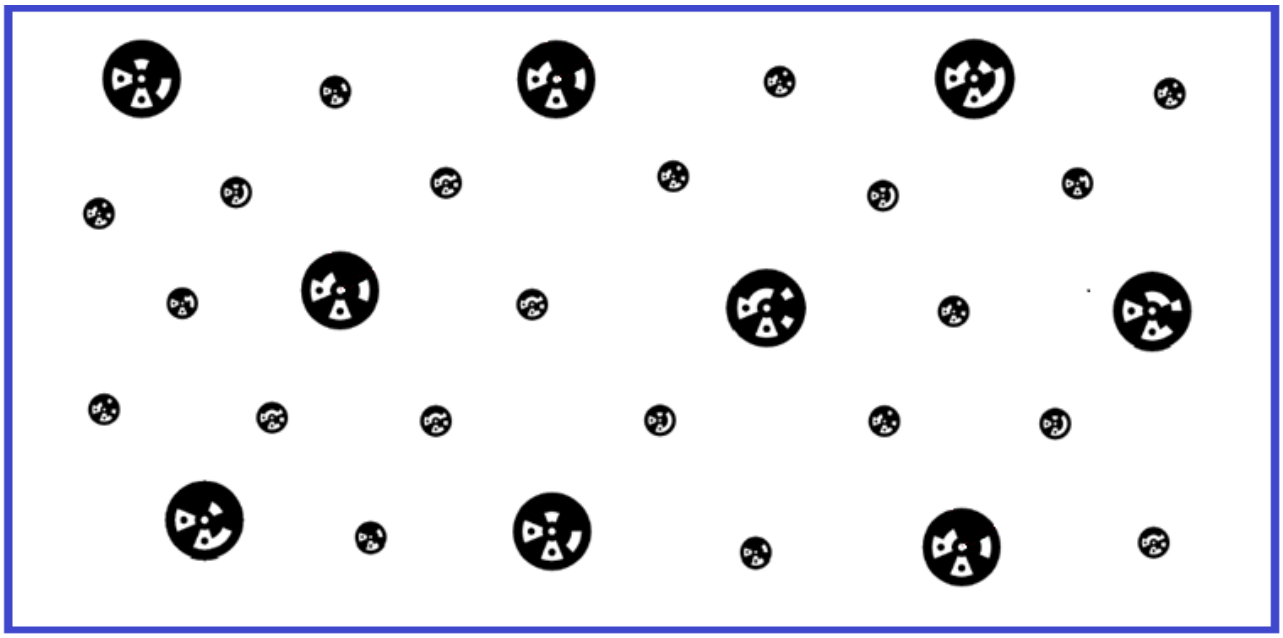


Figure 5 Constellation Deploying Dense Array of Smaller Fiducials and Sparse Array or Larger Fiducials

Each constellation requires you to make judgments about how to lay out the fiducials. The guidelines in this section and the steps outlined in the next section help you make the right decisions when creating your constellation.

3.3 Creating the Constellation

To design a constellation, you take several steps:

1. Based on the focal length of your optical inertial sensor and the size of your fiducials, determine the minimum distance from the tracker you should place any fiducial (see Section 2).
2. Select a location for the constellation by estimating that it needs an area of at least D × D, where D is the distance from the optical inertial sensor that a fiducial should be. For the most accurate detection of position and orientation during tracking, a minimum of six fiducials should be within the optical inertial sensor's 130° field of view at any time throughout the expected motion of the tracker.
3. Within the area where you plan to locate the constellation, determine where you want the forward centerline of your constellation.
4. Place the fiducial whose center should be located at the origin of the constellation on the centerline in the back section of the constellation. This fiducial is the *origin fiducial*. Secure the fiducial to the location.
5. Retrieve the fiducial ID number of the origin fiducial and label the fiducial with it. You can place a matte label or written label next to the fiducial that does not interfere with its readability.
6. Place a second fiducial on the front section of the centerline. This fiducial is the x axis fiducial, also called the *forward target*. The forward target is always on the x axis in front of the origin. Retrieve the fiducial ID number of this forward target fiducial and create a label for it, just as you did for the origin fiducial.

   You later enter the ID numbers for the origin and forward target fiducials in the mapper software. The software uses these fiducials to establish the location of the x axis, the forward axis of the constellation.

   You can, alternatively, place a fiducial on the x axis *behind* the origin fiducial as the x axis fiducial. This fiducial is called a *rear target*. You need either a forward target or a rear target in your constellation, but not both.
7. Distribute the remaining fiducials evenly throughout the remaining constellation field, being sure to follow the guidelines outlined in the previous section. For a step-by-step example, see Section 3.3.2, Determining Best Density of Fiducial Distribution in Constellation.

NOTE

Note that the position of a fiducial is defined by the coordinates at the center of its circular shape.

3.3.1 Generating Sample Constellation

This section walks you through the decisions required to create a constellation for using a optical inertial sensor with a range of 20 inches to infinity.

1. Your optical inertial sensor's minimum focal length is 20 inches, and you want to be able to have it see fiducials from 2 to 8 feet away from the wall or ceiling. The calculation of the size fiducials you need is based on a tracking range of 20 to 25 times the fiducial diameter. To reverse the calculation, you can take the distance you need and divide by 20 to 25. You can divide by 20 to give yourself the most conservative estimate:

   Since 2 ft = 24-inch minimum focal point,
   24 inches ÷ 20 = 1.2 inches or 30.48 mm—closest size fiducial is 35 mm (1.375 inches)

   Since 8 ft = 96-inch maximum focal point,
   96 inches ÷ 20 = 4.8 inches or 121.92 mm—closest size fiducial is 127 mm (5 inches)

   So, you're going to work with the three fiducials recommended for an optical inertial sensor with a 20-inch minimum focal length—35 mm (1.375 inches), 76 mm (2.99 inches), and 127 mm (5 inches). The middle size (76 mm) fiducials will cover distances in between the minimum and maximum focal points.

2. The location you're planning to work in needs to be a minimum of 8 ft × 8 ft or 64 sq ft. At a minimum distance of 2 ft, since the optical inertial sensor can see in a 130° field of view, it can see an area approximately 8 ft wide/high (in every direction) along the wall (see figure below), allowing ample space to include a minimum of six 35 mm fiducials with 5 inches (diameter of largest fiducial) between them in its field of view, since the calculation below shows they only require 2.5 ft of space to be adequately distributed:

   (6 × 1.375 in) + (6 × 5 in between them) = 30.825 in (2.5 ft) of space required.

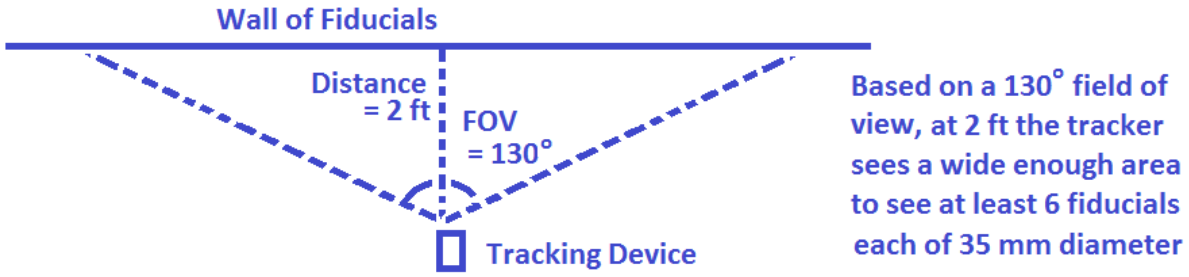


Figure 6 Sensor's 130° Field of View, 8 ft in Every Direction from 2 ft Away

At the maximum distance of 8 ft, the optical inertial sensor has a much wider field of view, so as long as you can fit six 127 mm (5 inch) fiducials in that field of view, it looks good:

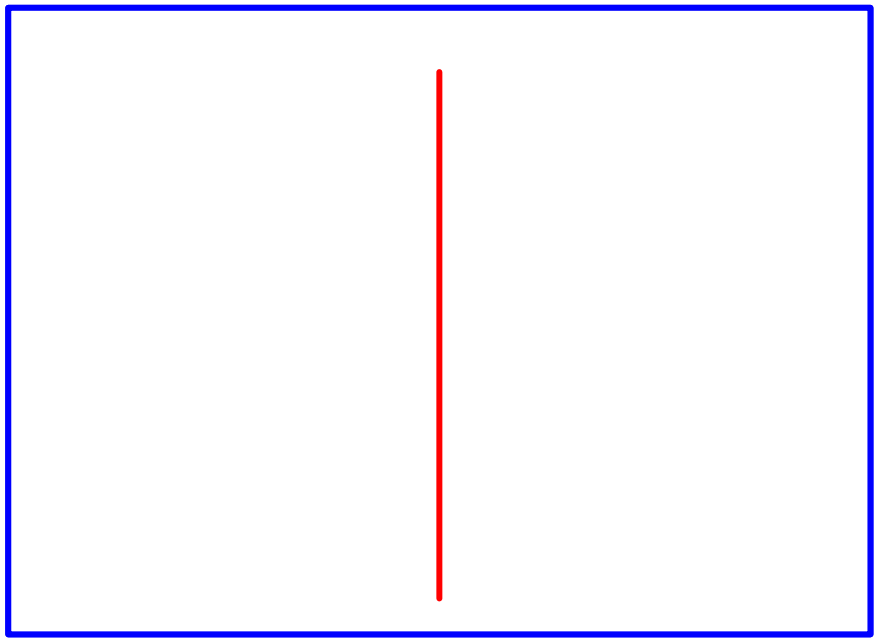
6 × 5 in = 30 in + 30 in of space between them = 60 in (5 ft) of space required.

You need only 5 ft of space to distribute six 5-inch fiducials a minimum distance apart.

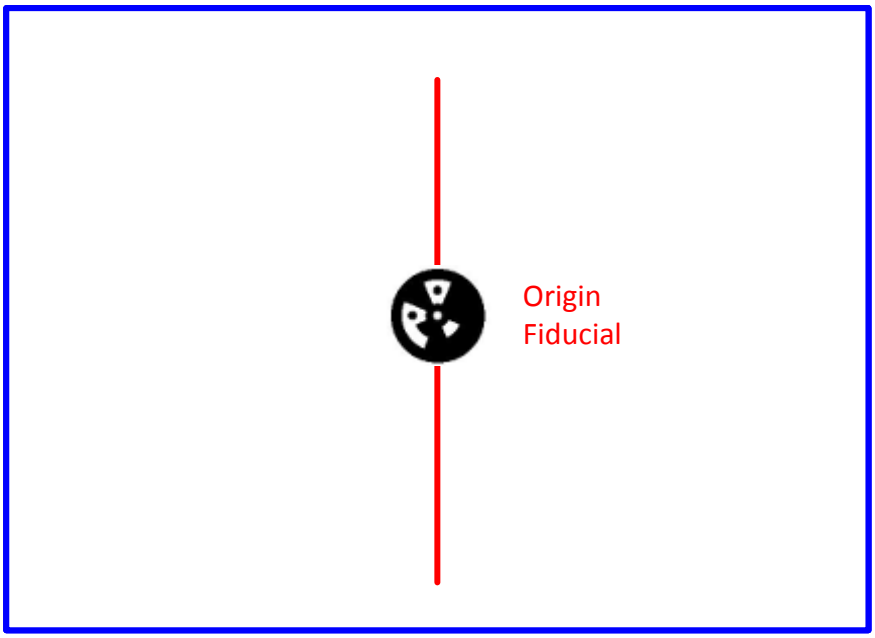
For viewing from the middle distances of 3 to 7 ft from the optical inertial sensor, you should be able to fit at least six 76 mm (2.99 inch) fiducials:

6 × 3 in = 18 in + 30 in between them = 48 in (4 ft) of space required.
6 × 7 in = 42 in + 30 in between them = 72 in (6 ft) of space required.

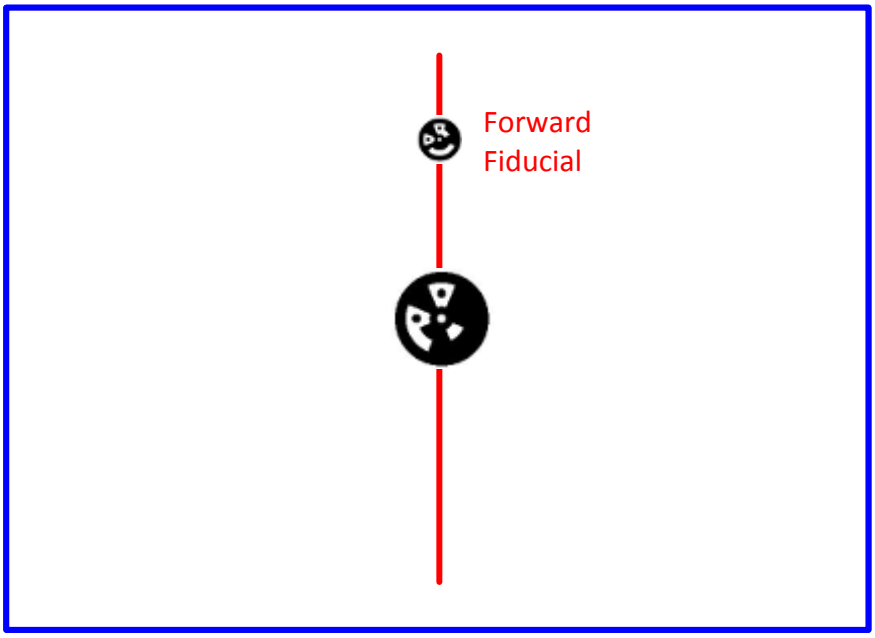
3. Within the area of the constellation, you place the front-to-back centerline.



4. Next, you position the origin fiducial in the constellation and label it.



5. Now add the forward x-axis fiducial, showing the direction of the x axis:



6. Now you distribute the remaining fiducials throughout the constellation area. You should measure the distances between the fiducials to be sure they meet the minimum required. For more guidance, proceed to the next section, 3.3.2, on Determining Best Density of Fiducial Distribution in Constellation to help you with density of fiducial distribution.

NOTE

In every constellation, the x axis points forward, the y axis points to the right, and z axis points down. The next figure shows the x, y, and z axes for a constellation placed on the ceiling.

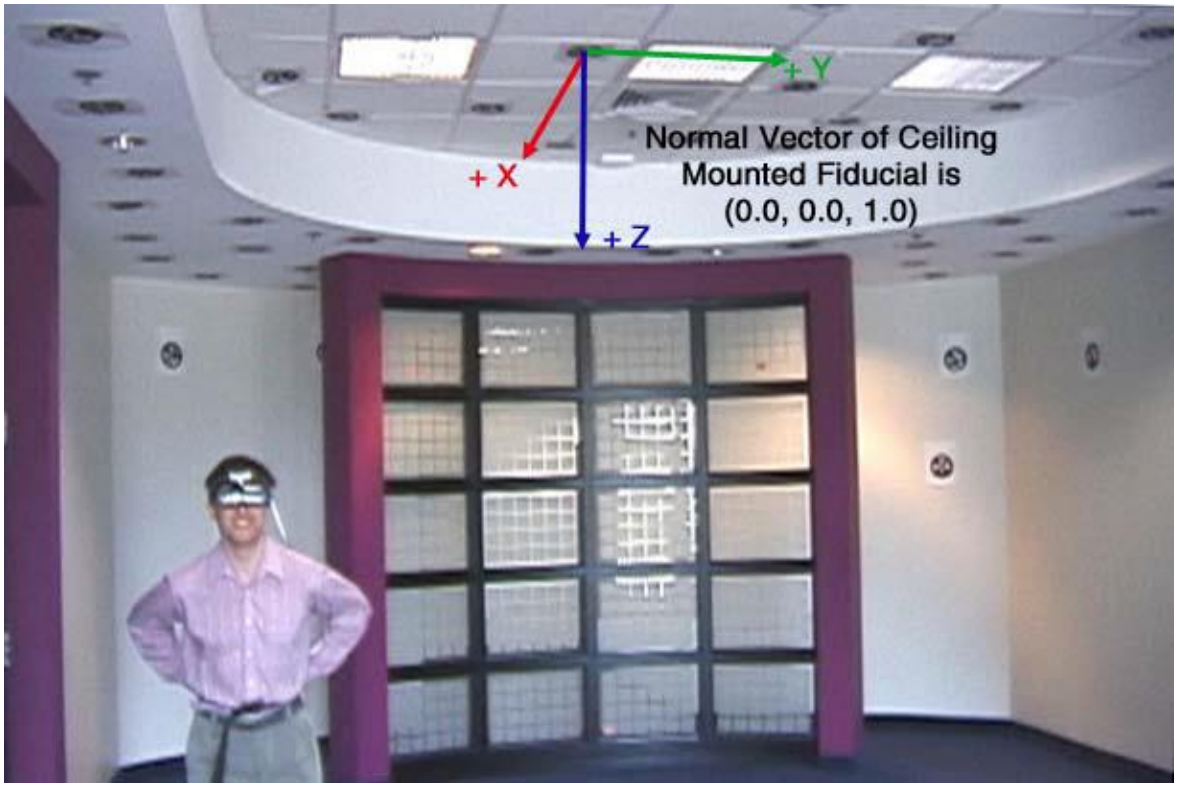


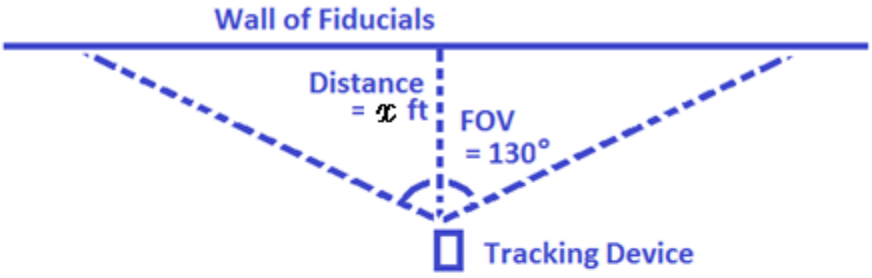
Figure 7 Location of X, Y, and Z Axes of Constellation That Has Been Placed Mostly on Ceiling

3.3.2 Determining Best Density of Fiducial Distribution in Constellation

How many fiducials of a particular size should you use in a given size area?

You can break down Step 6 from the previous section into a few more steps. For purposes of this example, you could use the three sizes of fiducials that are appropriate for an Optical Inertial Sensor with a minimum 20-inch focal point. And this time, first distribute them over a larger area, one that is 24-ft wide by 20-ft high and where a subject can stand as close as 20 inches to the wall (or ceiling) or as far away as 14 ft from the wall.

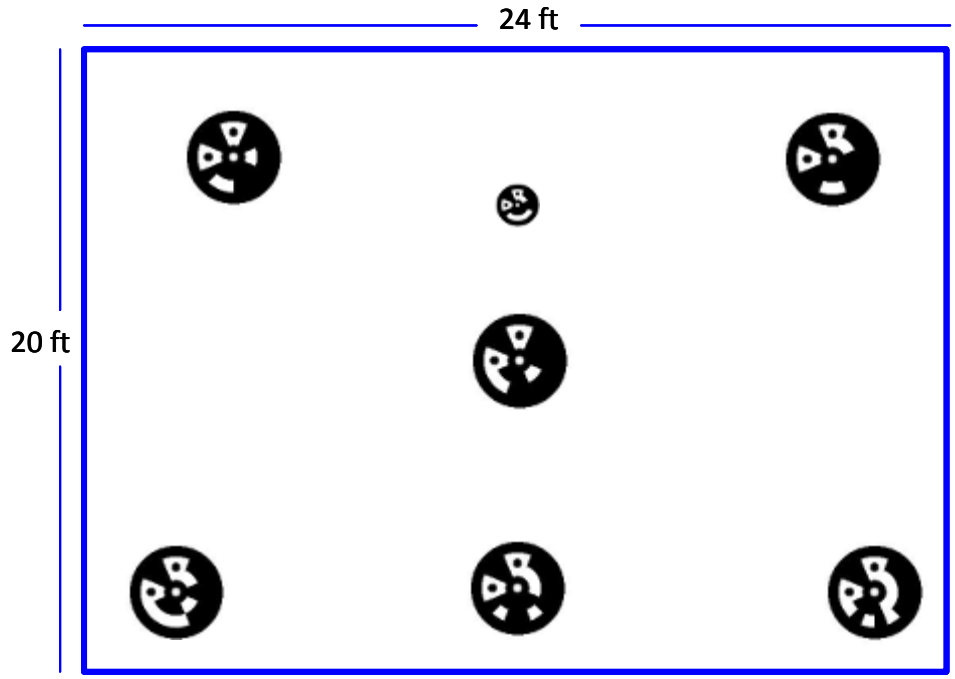
Determine the size of the field of view of the Optical Inertial Sensor when it is 14 ft from the wall and be sure that at least six of the largest fiducials (most visible from greatest distance) are in that field of view.



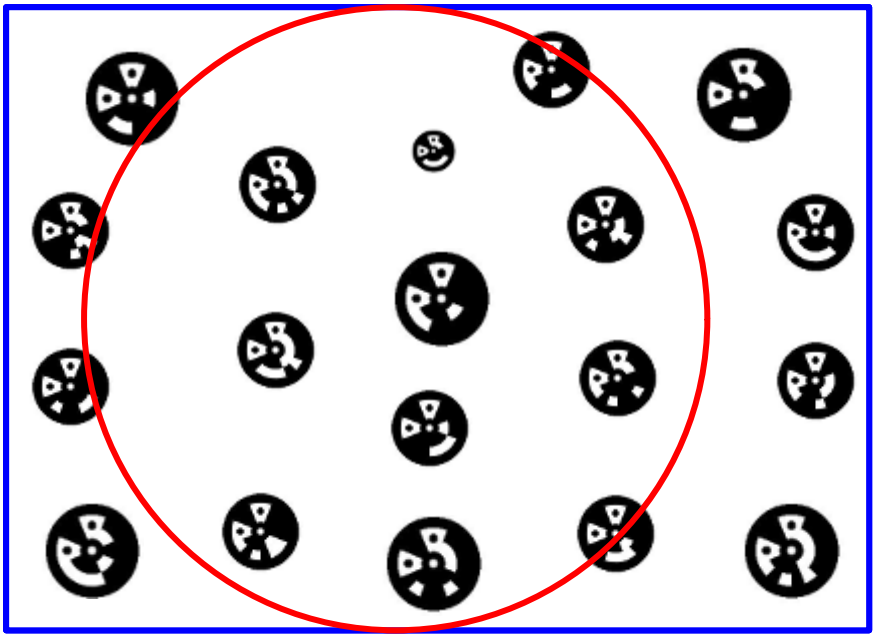
Distance x ft	Diameter of FOV
2 ft	~ 8 ft
3 ft	~ 12 ft
4 ft	~ 16 ft
5 ft	~ 20 ft
6 ft	~ 24 ft
7 ft	~ 28 ft
8 ft	~ 32 ft
10 ft	~ 40 ft
12 ft	~ 48 ft
14 ft	~ 56 ft

At least 6 fiducials must be in the Optical Inertial Sensor's field of view at the appropriate distance.

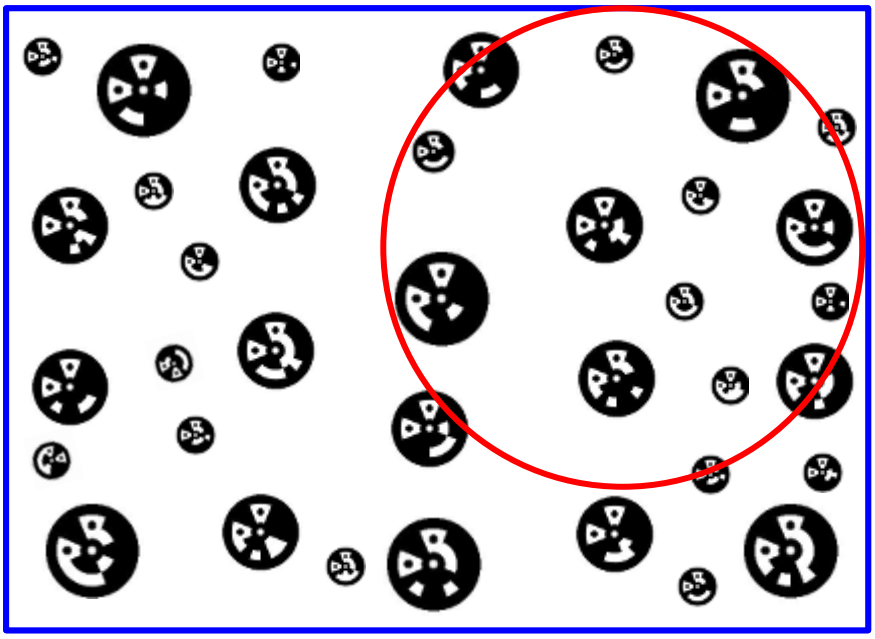
Based on the sizes of the field of view at each distance, you can see that because the field of view of the Optical Inertial Sensor at 14 ft is larger than the 24 x 20-ft area of the wall of fiducials, you need only place six of the largest fiducials in the entire area and disperse them reasonably evenly to have a full view at 14 ft. In this example, the origin fiducials is one of the six 127 mm fiducials, shown in the next illustration.



As you move in closer to, for instance, 5 ft from the wall, the Optical Inertial Sensor begins to have trouble seeing all six of the largest fiducials, because its field of view shrinks to 20 ft and the full width of the wall is 24 ft. At this closer viewing distance, you can add the middle size fiducials, being sure that at least six are visible in every section of the wall with a 20-ft diameter. The next illustration superimposes a circle to show the 20-ft diameter field of view. Check that the field of view contains at least six fiducials of the middle size.

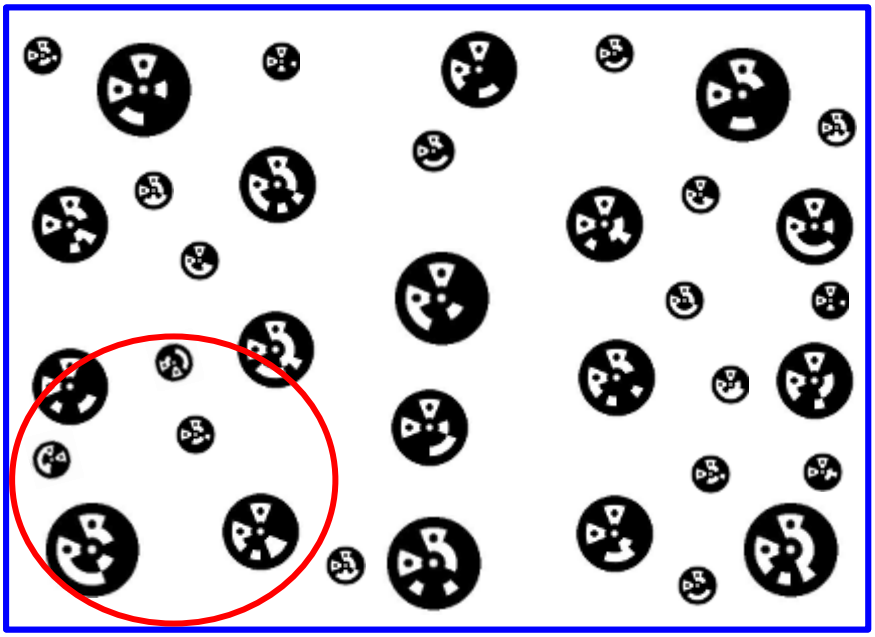


Notice that even when you move the field of view to the left, it always contains at least six fiducials of the middle size.



When you move the Optical Inertial Sensor in closer to the wall, at a 4-ft distance, the field of view's diameter shrinks to 16 ft, shown by the circle in the illustration below.

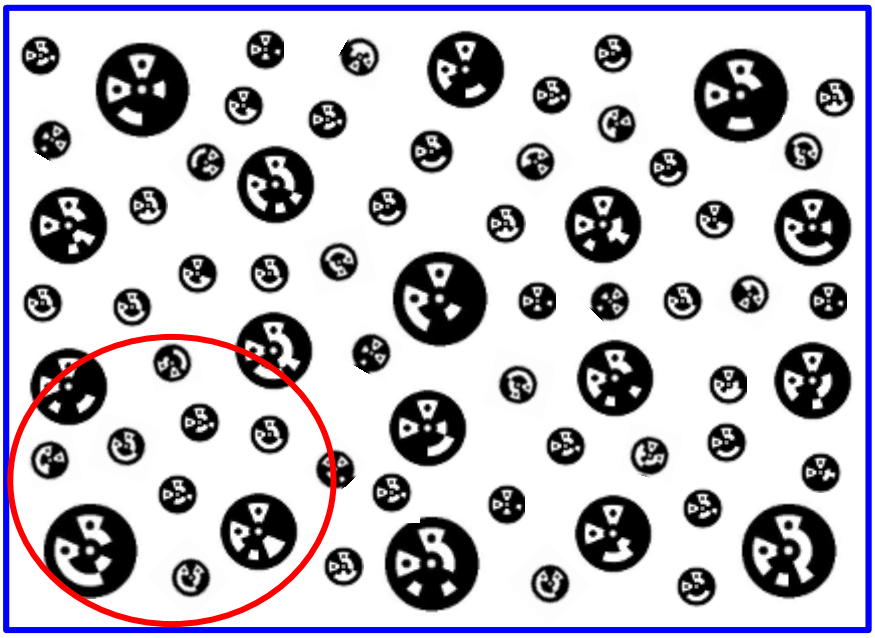
At this distance, you can see that there are only four fiducials of the middle size in the field of view, but if you add the smallest fiducials, you can see at least six fit into this field of view almost no matter where you move the field of view. If you move the field of view to a location where it includes only four or five fiducials, you should add more fiducials, carefully spacing them so that they are not too close together. If six mid-size fiducials do not fit in the field of view, use the smaller ones.



At the closest range of between 20 inches and 2 ft from the wall, the field of view's diameter shrinks again, this time to around 8 ft.

As shown in the next illustration of this example, after adding some of the smallest size fiducials for this particular Optical Inertial Sensor, this closest field of view does not yet contain at least six of the smallest fiducials, so you would add more to ensure the Optical Inertial Sensor sees each section of the wall at this close distance.

The modified constellation would look as shown below:



As you can see, the density of the fiducials depends on both the size of the fiducial and the size of the field of view. And the size of the field of view depends on the distance that a subject is standing from the wall or ceiling in the environment.

After you have created a few constellations, you develop a feel for the appropriate density of fiducials required.

4. Understanding Forward and Backward Target Alignment

To align the constellation, in the software you can assign a fiducial whose center is the origin of the constellation (based on the reference frame—like a geometric coordinate system).

In some constellations, you might want to align the constellation with a *forward target*, which is a fiducial in front of the origin fiducial.

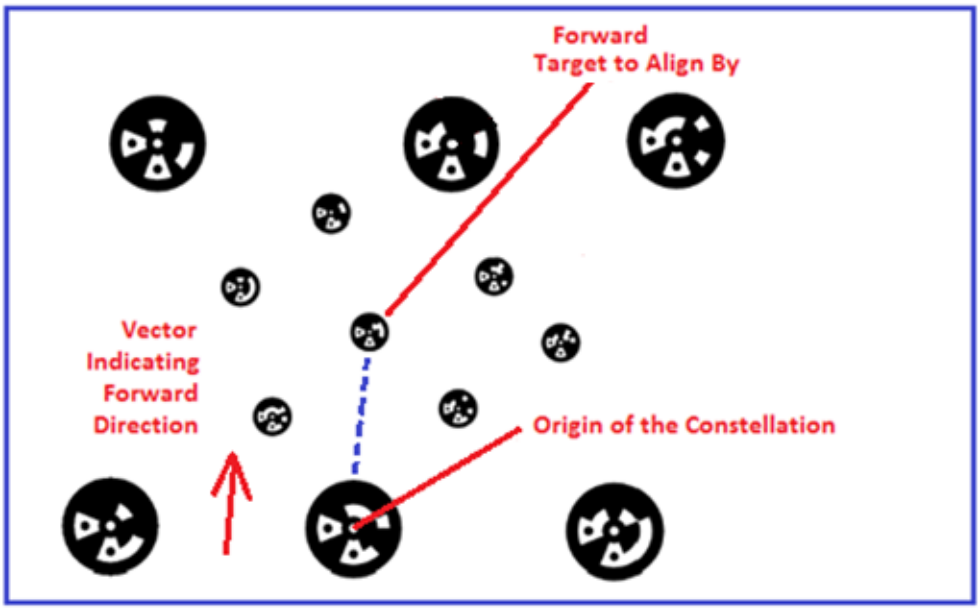


Figure 8 Illustration of Aligning by Forward Target

If you do not have a fiducial in front of the origin fiducial, but you do have a fiducial that lines up *behind* the origin fiducial, you can align the constellation by a *rear target* (see next figure).

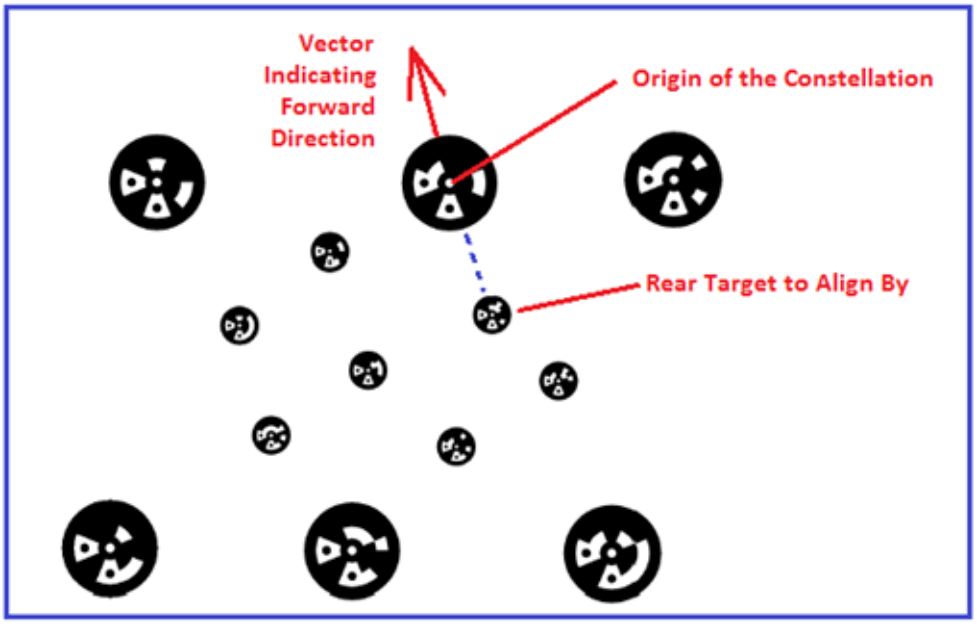


Figure 9 Illustration of Aligning by Rear Target

5. Evaluating Performance of Your Constellation Design

You can use SFStudio to evaluate the performance of your constellation design. If you have not set up SFStudio, refer to the *SFStudio User Guide* for installation and operating instructions.

Begin by having the optical inertial sensor view the constellation. Translate the sensor over the constellation at the appropriate distance or distances. Collect some initial data. It does not take more than a few minutes to have enough data to show graphs in SFStudio.

To evaluate your constellation design, open the **Pose Recover Stats** (from the **Display** menu).

The geometric dilution of precision—GDOP, **praGdop** in the **Pose Recovery Data** table in SFStudio's **Pose Recover Stats**—should be as low as possible. Look for a GDOP consistently below 2 to indicate the right performance for *high performance* applications and GDOP below 5 for *typical* performance applications. Larger GDOP values are acceptable for applications requiring minimal fiducials.