First Responder UAS 3D Mapping Challenge

Stage 2.2: Prototype Building & Safety Evaluation

3D Mapping Test Lane Guidebook

Final Version

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Introduction

For this competition stage, you will demonstrate your 3D mapping capabilities by constructing and operating your uncrewed aerial system (UAS) on a test lane per the specifications described in this document. This test procedure will evaluate your UAS design and sensor capabilities, mapping at a rate of two feet per second. You will then evaluate map coverage gaps, dimensional accuracy, and detection reliability of different sizes of objects. This document is designed to help you build, set up, fly the test lane, and evaluate mapping capabilities. Once constructed, you may practice as much as you like and submit your best video results. Submit a completed video even if portions of the testing procedures are unsuccessful. Please pay close attention to the scoring requirements and how this test fits into the overall deliverable for this competition stage.

Note: This test is only for evaluating your 3D scanning capability and is not designed for multiple mapping vehicles. In the interest of safety, repeat this test with each vehicle rather than having multiple mapping vehicles in one space. You may reduce the scanning speed of individual vehicles so that the average scanning speed remains 2 feet per second (ft/sec). (e.g., for two vehicles, perform a separate test with each, and move each at a minimum of 1 ft/sec.). If your primary UAS (and any additional 3D scanning vehicles) require a support vehicle for proper operation (data processing vehicle, etc.), it may be powered on and remain stationary between the 0 and 2.5ft line.

Materials List:

The following is a list of materials and quantities needed for building the apparatus. Fabrication of these parts is explained further in the next section:

1. One (1) hallway-like indoor space:
    a. Well Lit.
    b. At least 20 feet (ft) long + extra area for the operator (the operator may have a direct line of sight to the UAS).
    c. Flat and square (horizontal/vertical) surfaces.
    d. A height and width of 7 ft to 12 ft.
        i. Deviations of up to 2 ft in width or height are allowed as long as you document this deviation, and the space satisfies the rest of the requirements.
        ii. The area does not need to be enclosed as long as there are suitable surfaces on the sides and ceiling for mounting the 2D and 3D targets, and the features you add will remain stationary and undisturbed.
    e. There are no restrictions on the features of the space as long as:
        i. There is space for the 2D/3D features that you will add to the area, with clearance to measure the distance between them with a tape measure.
        ii. The UAS will have an unobstructed path for mapping the space.
        iii. No assistive mapping features will be usable in the environment.
            1. Locating items/devices must be covered or removed.
            2. Examples are retroreflective tape, AR tags, survey markers, or fiducials.
        iv. Examples of allowed items: furniture, chairs, shelves on/against walls, patterns on walls, covering over reflective surfaces like glass windows, blocking or closing doors, etc.

2. One (1) Roll of Painter’s tape for creating line markers on the floor of the hallway; other methods for marking lines are acceptable if the color and width of the lines are visible in recorded videos.
3. Twenty (20) 2ft X 2ft Panels to create five (5) sets of mapping fiducials.
    a. You may make these panels from any suitable flat, rigid material, reinforced as needed, and held in place so they will not move when subjected to the drone’s airflow.
    b. Suitable materials include foam-core board, fluted plastic, insulation foam panels, plywood, expanded PVC, or corrugated cardboard, held together by tape, glue, or screws (may be painted or covered as desired).
4. One (1) Square (framing square recommended) to assist with assembling mapping fiducials
5. Ten (10) Printed 2D targets (digital copies provided) on regular 8.5 inches x 11 inches (in) copy paper
6. Material to create 3D Objects of Interest: three (3) 8in, three (3) 4in, and three (3) 2in 3D Cubes:
    a. You may create these cubes from suitable material to keep the dimensions ± ½in.
    b. Examples: wood, cardboard, polystyrene foam, etc., reinforced as needed and held in place so that they will not move when subjected to the drone’s airflow.
7. Three (3) Video recording devices set to record in at least 1280 x 720 pixel resolution
8. One (1) 20ft (or greater) Tape Measure
9. One (1) Caliper
10. One (1) Calculator
11. One (1) Stopwatch with a split function
12. One (1) Portable media storage device to save the map deliverable

Fabrication:

Mapping Fiducials

1. You will create five (5) fiducials, each constructed from four (4) 2ft x 2ft flat panels:

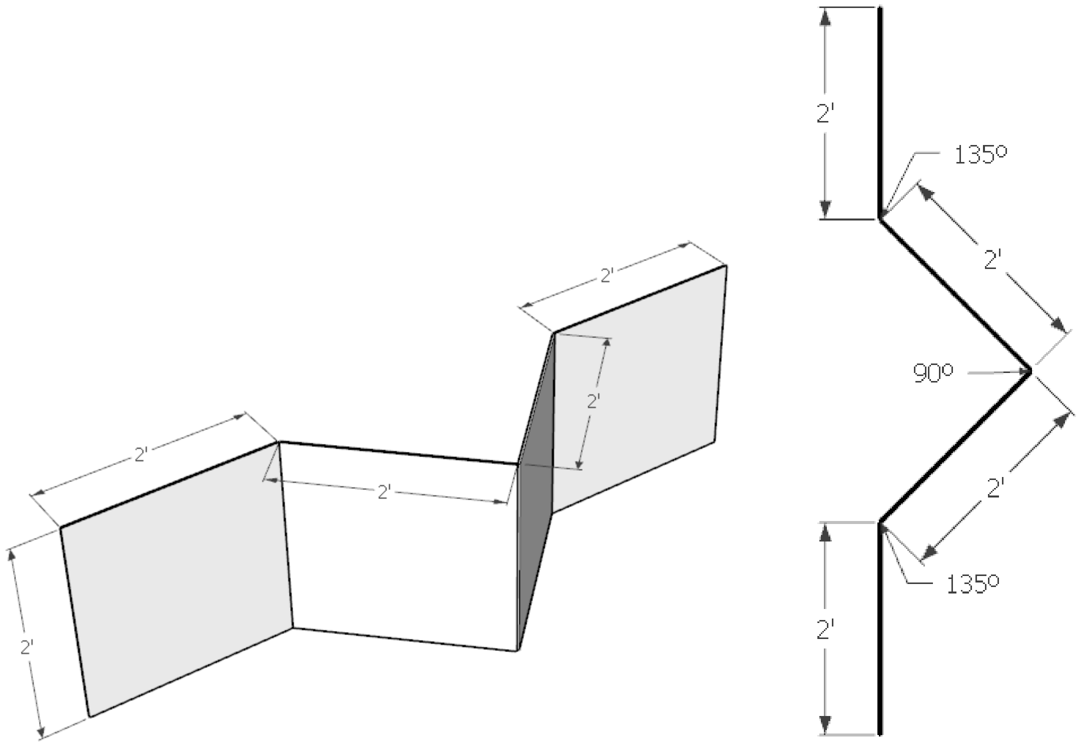

Figure 1 Fiducial Measurements

2. Start by attaching two of the panels at a 90° angle.
    a. Depending on your material type, you may need considerable reinforcement within the inner structure to maintain this angle when subjected to UAS wind loads; it shall remain fixed with an accuracy of ± 5°.
    b. The fiducial surfaces shall exhibit no surface deflection greater than 1in.
    c. A framing square may assist in assembly.
3. Attach the other two panels to the 90° section at an angle of 135° so they will lay flat against the surface to which they will be applied.
4. Repeat for the other four (4) fiducials.

2D Targets

1. You will print a series of ten (10) 2D targets onto high-quality copy paper; a PDF file is attached.
    a. Print one sheet first to measure the print accuracy before printing the remaining sheets.
    b. Using a caliper, ensure the gaps in the five (5) ring sizes (the openings in the Optotypes/Landolt rings) are accurate to 0.01in; adjust print scaling as necessary.
        i. 0.79in
        ii. 0.31in
        iii. 0.13in

iv. 0.05in
v. 0.02in

Figure 2 Outer Ring-Gap Measurement (1 of 5 on the sheet)

3D Objects of Interest

Create nine (9) 3D objects of interest, three (3) of each of the following, verifying the final dimensions are within ± ½in. They must be identical and uniform in color (may be painted or covered as desired):

1. Create an 8in x 8in x 8in cube
2. Create a 4in x 4in x 4in cube
3. Create a 2in x 2in x2in cube

Setup:

Hallway Marking

1. Start by selecting your hallway-like space and selecting a starting (zero) point.
   If space is limited, this may be an end wall as long as the operator has a safe space to operate outside the 20ft section (such as an adjoining room).

2. Using Painter's tape, mark the starting line along the entire hallway width, perpendicular to the side walls:

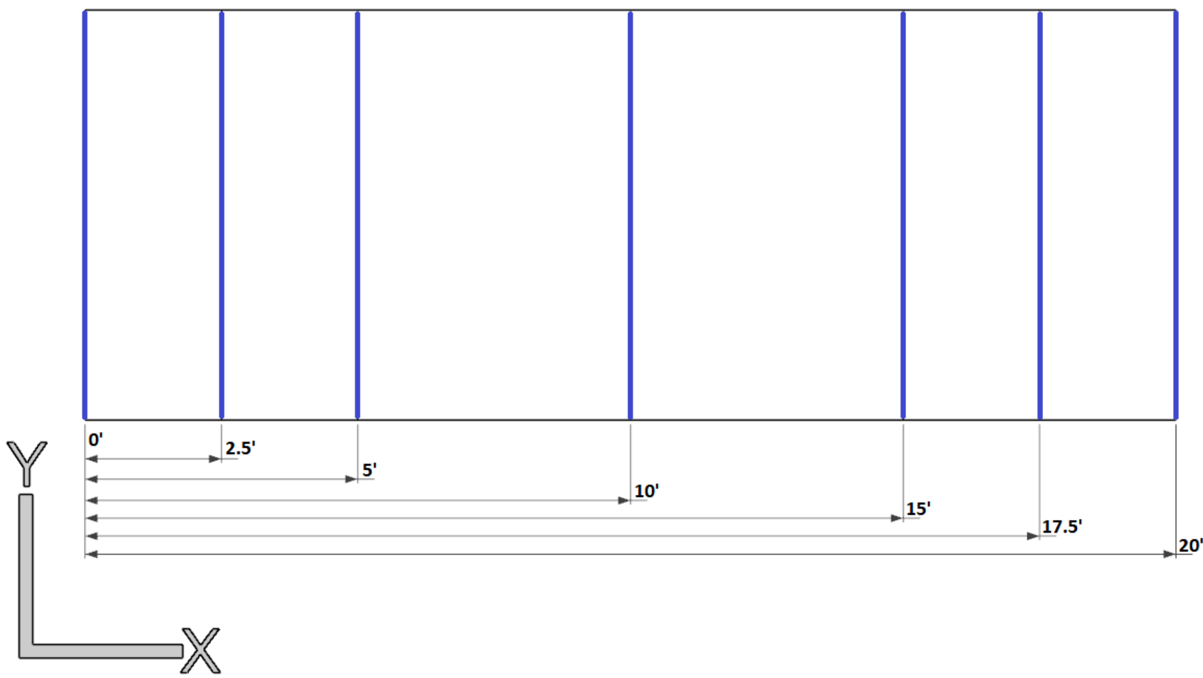

Figure 3 Line-Marking of Test Lane

3. Next, measuring from the starting line, add six (6) additional line markers along the width of the hallway at the following locations. The locations of the lines should be accurate relative to the <u>starting line,</u> as shown below:
    a. 2.5ft ± .25in
    b. 5ft ± .5in
    c. 10ft ± 1.25in
    d. 15ft ± 1.75in
    e. 17.5ft ± 2in
    f. 20ft ± 2.5in

Fiducial Placement

Next, one (1) fiducial will be placed in the center of the floor, and four (4) will be placed against the walls with an X-direction accuracy of 1in relative to the center of the lines. Attach them with tape or other sturdy means, reinforcing the structure as needed to hold the requisite shape:

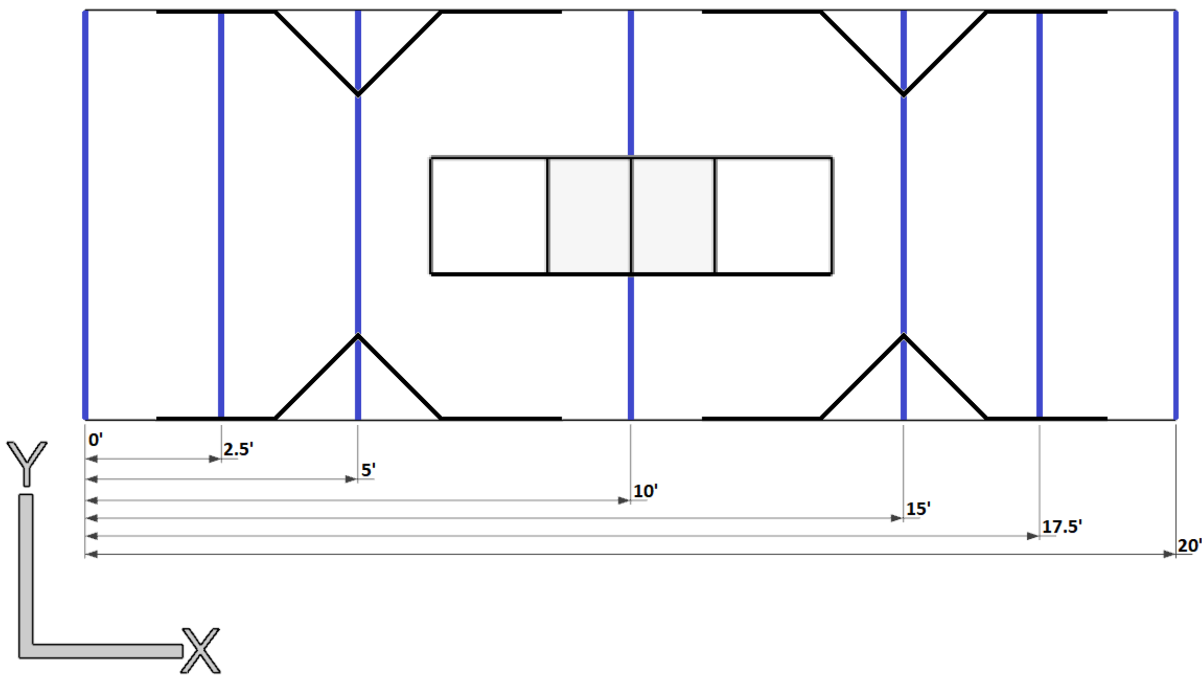

Figure 4 Fiducial Placement within Test Lane

1. As shown in the center above, secure a fiducial on the floor at the 10ft mark.
    a. Center it in the Y-direction.
    b. Square it up with the center directly over the tape line.
2. Place four (4) fiducials against the walls at the 5ft and 15ft marks.
    a. Assuming a flat, uniform wall, each fiducial's parallel "wings" must not deviate from parallel by more than 2in over the entire length of the fiducial.
    b. If the walls are not flat and uniform, you may need to adjust the Y-direction of the fiducials to compensate, making them parallel to the other fiducials.
    c. You may adjust a wall fiducial along the Y-axis to clear any existing features (such as bookshelves, etc.) along the wall as long as the broadside remains parallel to the wall and the protruding corner remains on the line you marked earlier:

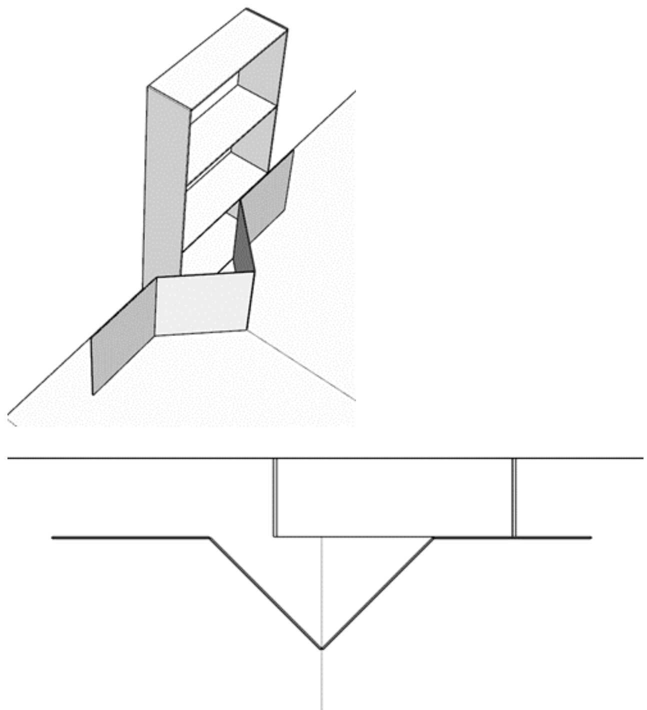

Figure 5 Example of Fiducial adjusted in the Y-direction to clear a bookshelf

2D Target Placement

Place the numbered 2D targets at any location/orientation within the following areas; make sure the paper is secure and lays flat (see the accompanying video to visualize the placement of the 2D targets):

1. Place #1 between the 2.5ft and 5ft lines on the floor.
2. Between the 5ft and 10ft lines, place #2 on the floor, #3 on the left wall, #4 on the right wall, and #5 on the ceiling.
3. Between the 10ft and 15ft lines, place #6 on the floor, #7 on the left wall, #8 on the right wall, and #9 on the ceiling.
4. Place #10 between the 15ft and 17.5ft lines on the floor.

3D Objects of Interest Placement

Place each set of 3D objects of interest following these guidelines:

1. The three cubes in the set shall be no more than 2ft apart.
2. The area around each set must be flat and clear to a distance of 6in.
3. Each set must rest on a coplanar surface and not move in the presence of air currents. If the surface is not coplanar, you may need to adjust the mounting or attach the group to a board (of appropriate size to meet the clearance requirements).
4. Mount each set in any orientation within the following areas:
    a. Between the 5ft and 10ft lines on the floor.
    b. Between the 10ft and 15ft lines on the floor.

c. Between the 5ft and 15ft lines on one of the walls, at least 2ft up from the floor and 2ft down from the ceiling.

Camera Placement

Note: You will later select one of these cameras for a walkthrough of the environment.

1. Camera #1 – Place this camera showing the operator interface, along with user interaction (the operator's hands) and the real-time map progress rendering. The map must be clear enough on camera to compare to the final 3D map deliverable.
2. Camera #2 – Place this camera near the 0ft mark, looking forward through the environment, showing the UAS taking off and the 5ft and 10ft fiducials.
3. Camera #3 – Place this camera near the 20ft mark, looking back through the environment to capture the UAS landing. The 10ft and 15ft fiducials should be in view.
4. Camera #4 – Existing onboard camera facing out towards the nose of the UAS.

The camera video streams must be combined into a single quad-screen video composited from the different views. This may be accomplished by using a video multiview processor that combines multiple inputs into one video output or time-syncing and combining the separate video streams with video editing software later. The camera closest to the pilot must also record sound. This combination of views and a single audio stream will be required to complete the Testing Procedure portion of your demonstration.

Test Procedure (Test Procedure Video A)

In Steps 1-5, you will take video footage of taking measurements just before the flight. You will need a helper for tape measurements.

1. Select one of the cameras and begin recording.
2. Walk through the environment, noting each piece of test apparatus.
3. Record the following ground-truth measurements on camera to an accuracy of 0.5in without stopping the video. You will later need to record the reference dimensions in your scoresheet. For fiducial measurements, you will measure to the top corners of fiducials. The floor fiducial has both upper corners exposed; you will use the nearest of the upper corners when taking measurements 7-10, as shown in Figure 6. Left and right orientations are referenced from the starting line. Note the fiducial measurements may not be symmetrical if you need to adjust a fiducial along the Y-axis earlier to clear existing features in the space.
    a. Ref#1: The distance between the left and right fiducials on the 5ft mark.
    b. Ref#2: The distance between fiducials on the left-side wall (at the 5ft and 15ft marks).
    c. Ref#3: The distance between fiducials on the right-side wall (at 5ft and 15ft marks).
    d. Ref#4: The distance between the left and right fiducials on the 15ft mark.
    e. Ref#5: The diagonal distance between the left fiducial at the 5ft mark and the right-hand one at the 15ft mark.
    f. Ref#6: The diagonal distance between the right fiducial at the 5ft mark and the left-hand one at the 15ft mark.
    g. Ref#7: The distance between the left fiducial at the 5ft mark and the nearest upper corner of the floor fiducial at the 10ft mark.

h. Ref#8: The distance between the left fiducial at the 15ft mark and the nearest upper corner of the floor fiducial at the 10ft mark.
i. Ref#9: The distance between the right fiducial at the 5ft mark and the nearest upper corner of the floor fiducial at the 10ft mark.
j. Ref#10: The distance between the right fiducial at the 15ft mark and the nearest upper corner of the floor fiducial at the 10ft mark.

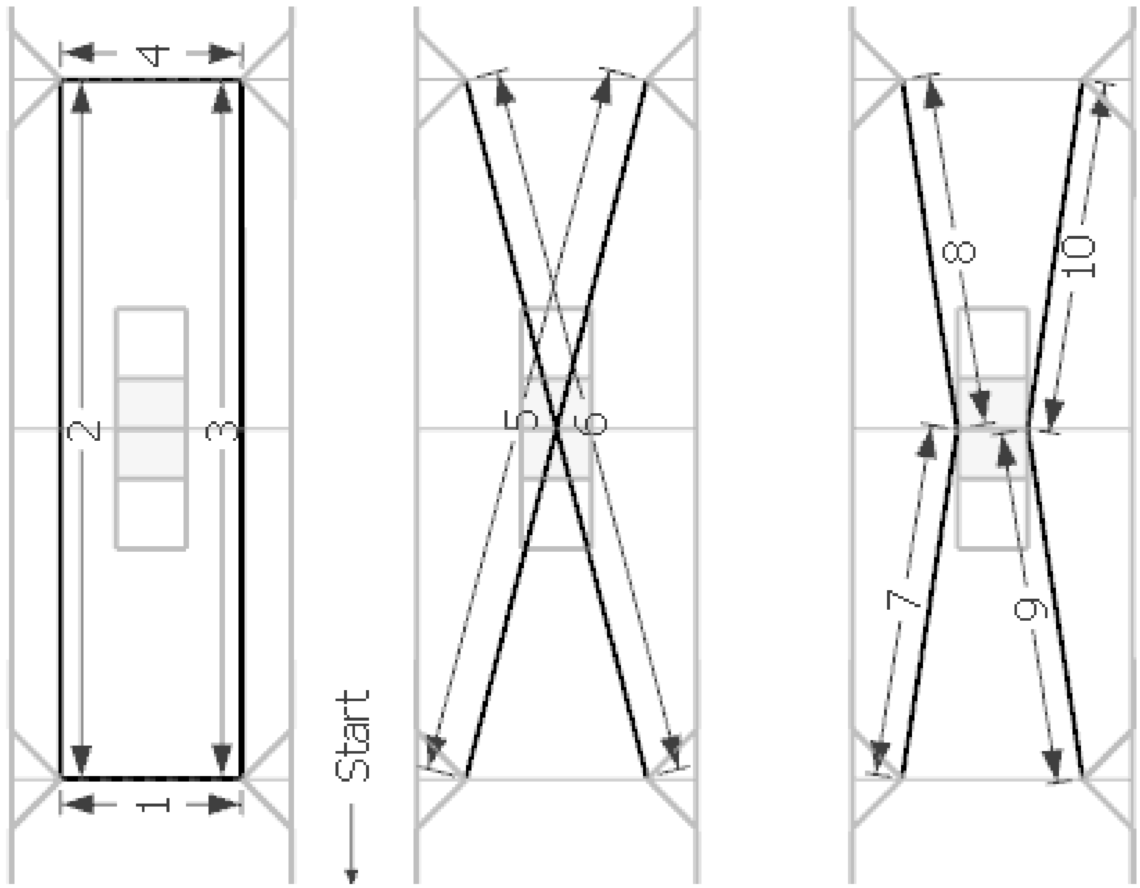

Figure 6 Fiducial Tape-Measurement

4. Place this camera back in position without stopping the video.
   a. **Start the other cameras**.
   b. Synchronize the recordings by clapping or turning off/on a light visible to all cameras.
5. Perform appropriate pre-flight safety procedures and arm the UAS.
6. Prepare a stopwatch and take off vertically. Stabilize and get to a desired altitude without crossing the 2.5ft line.
7. When the UAS begins to fly forward past the 2.5ft line to begin mapping, <u>start</u> the stopwatch; this must be visible on camera. **Important**: the UAS must map the <u>entire length</u> of the test lane. The mapping speed is evaluated between the 2.5ft and 17.5ft lines to ensure safety margins in a confined space.
8. The UAS may follow any path desired, under any combination of pilot-operated and autonomous control, as long as it completes the mapping of the 15-ft-long environment in 7.5 seconds (equivalent to progressing in a straight line at an average of 2 ft/s).

9. Press the <u>split-time</u> button on the stopwatch the moment the UAS passes the 17.5ft line and stops traveling forward. This action must be clearly visible on camera.
10. Land the UAS past the 17.5ft line while keeping the stopwatch running.
11. Stop the two environment endpoint cameras while keeping the operator camera running.
12. <u>Stop</u> the stopwatch once the operator completes map generation processing and ejects the portable media storage device; the stopwatch must keep running until the final deliverable is ejected.
13. Verify that the time between the split and the stop time is less than 30 minutes.
14. Stop the operator camera.
15. Compile and save the video files in the same folder as the map.

Measurement (Test Procedure Video B):

Next, you will take measurements from the map you generated (Note: the final map deliverable shall be submitted in addition to the video files and score sheet). Use a video camera as you demonstrate the process of taking the measurements in this section. Enter the results in the provided score sheet concurrently or after taking the measurements.

Surface Coverage Gaps

In the recorded map data, zoom in on each of the four panels of each of the five Mapping Fiducials (20 panels in total). Count the number of panels with gaps greater than 1x1ft, including missing points on the perimeter of the panels:

1. Zero (0) is the best possible score.
2. A panel that is not visible on the map at all is considered as having a gap.
3. Both dimensions must exceed one foot (e.g., 17in X 7in does not count as a gap).

Relative Dimensional Error

Within the map data, digitally reproduce the measurements you took of the fiducials in step 3 of the test procedure to an accuracy of 0.5in and enter the results next to the ground-truth measurements in the score sheet.

Object Detection

In this step, you will count the number of Optotypes/Landolt rings (2D) or Objects of Interest (OOI) (3D) that you successfully detect via your map data. Your scoresheet will compute the percentage undetected by subtracting the number of detected objects from the total number of objects, five (5) for each of ten (10) 2D targets (total of fifty (50)) and nine (9) 3D targets. Lower is better; 0 for each is the best possible measurement.

2D Targets

In the recorded map data, note the number of Landolt-C Optotypes readable of each size. Note: depending on your acquisition technology, the 2D objects may or may not be visible in your map data; the 2D test is only an exercise and not for your final mapping score. While outside the scope of this test, you should separately practice reading these via your real-time video stream. A Landolt ring is readable if the gap is clearly lighter in color than the rest of the ring. As the gaps can be detected, the upper row is readable in the example below. In the lower row, the ones on the far left and 4th from the left (circled) are not considered readable, as it is not possible to uniquely detect the gaps.

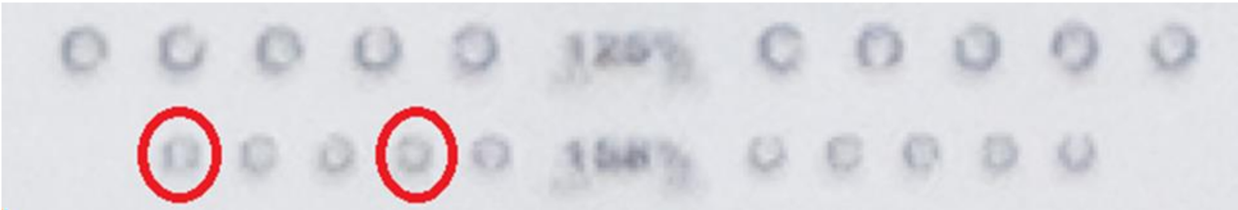

Figure 7 Example of Landolt-C Gap Detection

3D Objects of Interest (OOI)

In the recorded map data, note the number of OOIs that were detected of each size. There is a total of nine (9) OOIs, three (3) each of three (3) sizes. To be detected, an OOI must satisfy both the resolution and separation criteria:

1. Resolution: There must be enough points in the map to detect the object according to Johnson's criteria (the equivalent of two (2) scan lines):
    a. For a point cloud map, there are at least four (4) points in the map on at least one face.
    b. For a triangulated map, there are at least four (4) vertices on at least one face.
    c. For maps that use a different representation, contact the competition organizers for guidance on an equivalent criterion.
2. Separation (see Figure 8 for an example): Separation refers to how far the points or vertices representing the OOI in the map need to extend out of the surface on which it is mounted (the floor or wall), accounting for noise, distortion of the map, and smoothing effects. The OOI must extend at least half its edge length (2in, 4in, or 8in) beyond the surrounding surface noise:
    a. Identify the representative central point, **a**, on the OOI:
        i. Look at the surface of the OOI furthest from the surface on which it is mounted and identify the four (4) points or vertices in the middle of that face.
        ii. Identify the point or vertex out of these four (4) that is closest to the surface on which the OOI is mounted (e.g., for an OOI sitting on the floor, the lowest of the four (4) points or vertices in the middle of the top face). This is point **a**.
    b. Identify the representative point, **b**, on the surrounding surface.
        i. Identify the points or vertices within the region indicated in the diagram below.
        ii. Identify the point or vertex furthest from the surface on which the OOI is mounted (e.g., for an OOI sitting on the floor, the highest point or vertex in this region). This is point **b**.
    c. The Separation criteria are satisfied if the distance between points a and b, perpendicular to the surface on which the OOI is mounted (e.g., the height difference for an OOI sitting on the floor), is less than or equal to half of the ground truth length of the OOI (i.e., 2in, 4in, or 8in).

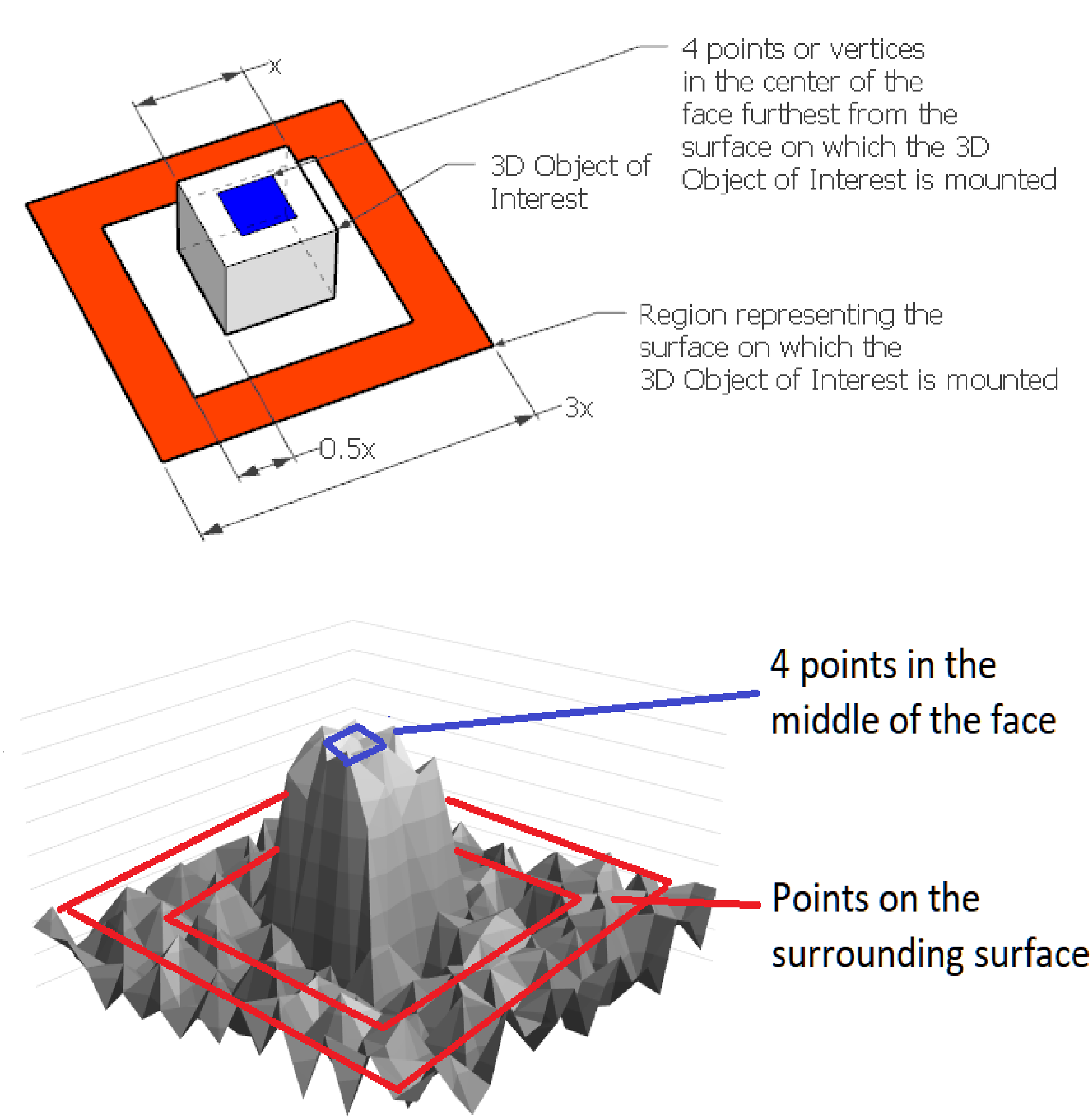

Figure 8 3D Object of Interest Detection

Mapping Speed

The time taken to map the environment is the split time noted in Step 9 of the test procedure. Enter this time into the scoresheet to obtain the average rate of progress. The minimum average rate of progress is 2ft/s (i.e., 7.5 seconds), with a preferred capability of 4ft/s.

The test procedure (Video 3: Test Procedure Video A), measurement video (Video 4: Test Procedure Video B), final 3D map deliverable file, and the other two required video files, Video 1: System Overview/System Safety Checks and Video 2: Indoor Flight, shall be uploaded to the online repository specified in the Contestant Portal (i.e., bestincrowd.com). All other submission materials shall be uploaded directly to the Contestant Portal.