**Memorandum**

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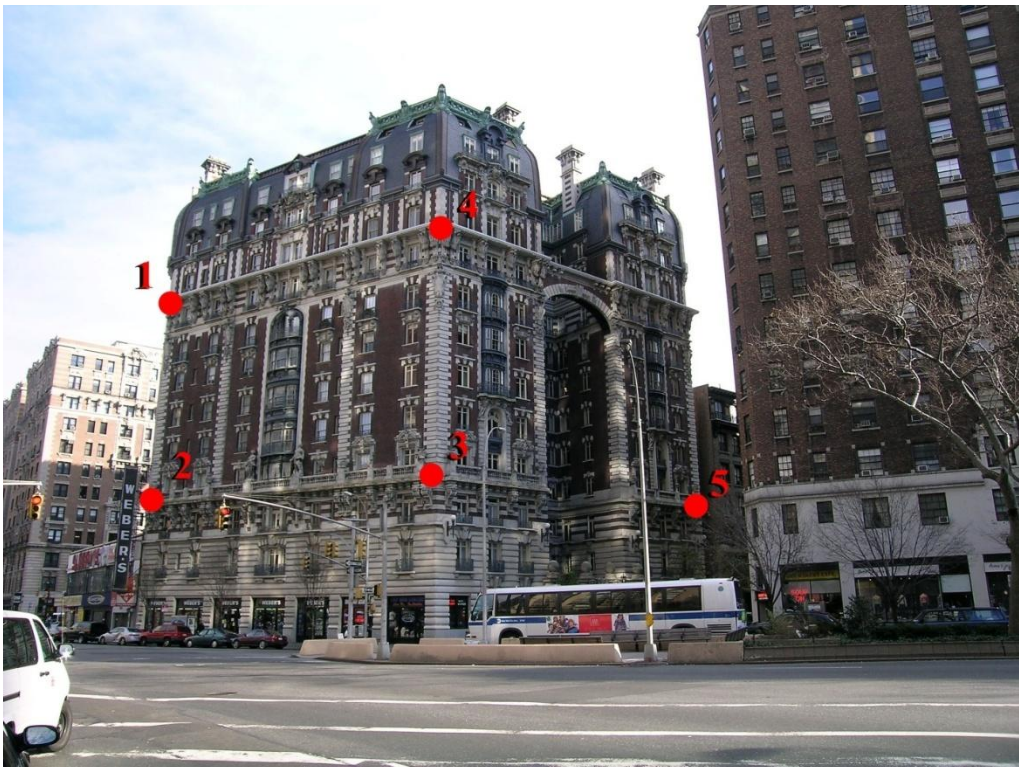
By: Brian Heagney

RE: The Camera Match Function in 3D Max for the Creation of Verifiable Digital Photomontage

In considering the use of the 3D Studio Max's camera match function, it may be best to think of the environment in which one is working in terms of extremes: close range urban settings; and vast rural landscapes. The appropriateness of the camera match function is quite different in these two environments.

Five references are needed to create a successful camera match using the camera match function. 3D Max's own documentation suggest that these five points should not fall on the same plane, but rather be spread out throughout the photograph. In order for five match-points to be spread out throughout the image and not exist on the same plane, it is best to imagine the points as the corners of a simple cube: four of the match-points representing the corners of one face of a cube, and the fifth match-point representing a unique corner of an adjacent face of the same hypothetical cube. Throughout this text, this configuration will be referred to as the optimal match-point configuration.



The camera match function works best when dealing with cases similar to the above photograph: a large rectilinear building with noticeable demarcations that do not include points where the building hits the ground (since those data can be either obscured or incorrect in the picture.)

Using the camera match function in a situation in the above environment should yield a successful and accurate camera match, not only because the references are configured in an optimal match-point configuration, but because there is little background, and we can locate ourselves fairly easily in space using clues from the image.

Since there is little background in the photograph, slight differences in the camera's pitch, roll or yaw will not yield significantly negative results in the photo-match, and any imperfections will probably be unnoticeable.  Further, since we are in a very urban setting, we can see that we are on a specific side of a specific street, near a significant number of landmarks, which makes it fairly easy to double-check our camera position.

Compare the above scene to the opposite extreme: vast rural landscape with very few manmade structures:

In such a rural setting, while we do see man-made structures scattered in the background, we should realize that there is error inherent in the camera-matching function will usually yield poor results in this environment.

## The experiment

To support this hypothesis, I have conducted a series of experiments. In these experiments I have cameras that have been placed using very high accuracy GPS units. These cameras were adjusted against references that were placed into the photograph that were likewise marked using very high accuracy GPS units. To see how well the 3D Max camera match functioned I have taken this photograph and compared cameras that were placed using the camera match function with the cameras that were placed using very high accuracy GPS adjusted with references.

To perform a camera match without the very high accuracy GPS points, the operator has a few options:

1. Create five match-points on one of the structures;
2. Create five match-points which are scattered among the different structures;
3. Insert poles or balloons with known coordinates and dimensions into the photo and create match-points to them.

For Scenario 1, one structure in the image is chosen for which we have either known coordinates or a 3D model.

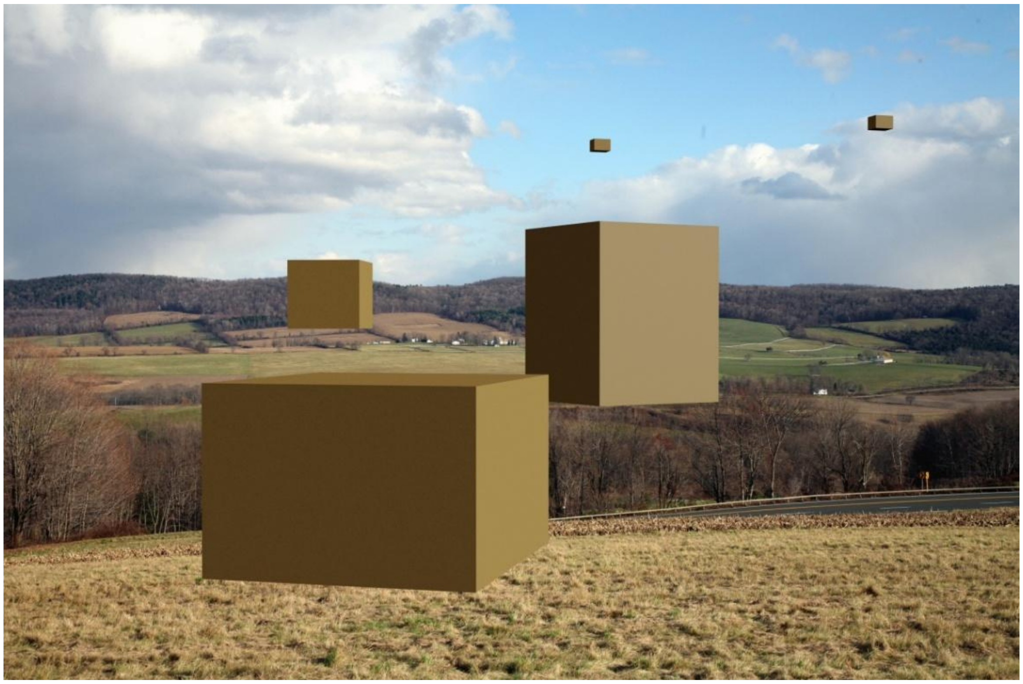
While it is not optimal to use match-points near the terrain (due to the fact that finished floor elevation in a CAD model may differ from where the structure actually hits the terrain) because both the structure type and distance from the camera, there are very few options for good match-points.

When performing a 3D Studio Max camera match in on this photo, using the above matchpoints, the camera-match function consistently failed, regardless of which structure was tested. When it fails 3D Max suggests that this failure could be the result of inaccurate measurements, or mixing up the match-points with the screen locations. After double-checking matchpoints and screen locations numerous times, it is my opinion that having all the match-points confined to such a small portion of the image is a detriment when using the camera-match function. It is for this reason that 3D Max documentation encourages using match-points which are scattered throughout the whole of the photograph.

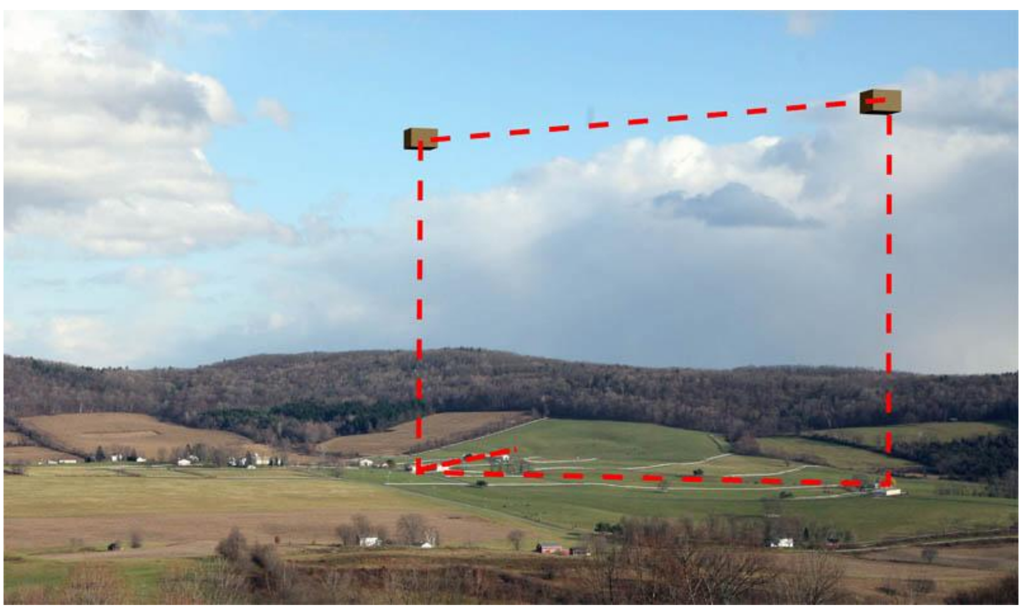
For Scenario 2, match-points were spread out across all of the structures in the scene as shown below.

This method also failed to produce a camera match numerous times, and it took great persistence in experimenting with the right sequence of match-points to use. More often than not, the camera-match function considered all of these match-points to exist on the same plane, even though there are elevation differences. Evidently these differences can be too slight for the function to notice. However, eventually the camera-match function did produce a camera to work with, and after manually adjusting the camera to match up with a good fit of the few buildings in the picture, it was roughly 850 feet away from where it should have been. Not an acceptable result by any measure.

To simulate Scenario 3, I created a few large cubes and rendered an image from the original virtual camera, and used that rendered image as my base:



The three cubes on the ground represent hard match-points in the foreground, middle ground and background. The two cubes in the air were used in conjunction with the man-made structures to complete the optimal match-point configuration.



Camera-Matching was tested for each of these scenarios (foreground; middle ground; background; barns and cubes in the sky; and combinations of all put together).

When using the corners of the cubes in the sky as match points, along with the corners of the barns below, a camera was created using the camera-match function with little difficulties. After manually adjusting the camera to better match the background image, the camera turned out to be 22’ away from where it should have been.

When using just the background cube for hard match-points, and manually adjusting the camera, I ended up with a camera roughly 35’ away from where it should have been. And when using the middleground cube for hard match-points and manually adjusting the camera, I ended up with a camera roughly 3’ away from where it should have been.

During the trials, for some unknown reason, the camera match function failed when trying to use the cube in the foreground.

After running the initial trials, each camera that was made was manually refined using all of the possible match-points (barns, houses, cubes) for references. After this process, all cameras were brought to be less than 6’ away from where they should have been.

## Conclusions

These experiments have led me to conclude that the **camera match function is not reliable in rural settings**, and only after much trial and error and utilizing a large number of match-points throughout the foreground, middle ground and background, the accuracy may be comparable to sub-meter accuracy of GPS technology.

For forensic purposes the camera match function may be the only solution for creating a photosimulation. In such a situation better results will occur where there are more reference points, especially when five or more of those points are in the optimal match-point configuration in the middle ground.

When not using GPS units with sub-meter accuracy when performing Verifiable Digital Photomontage in an extremely rural setting, the recommended data include: CAD data of existing structures in the original photograph; CAD data of proposed action; Hard match points in the foreground, middle ground and background where at least five hard match-points in either the middle ground or background consist of the optimal match-point configuration.

However, if GPS or surveyors’ equipment with sub-meter accuracy is used, the recommended data includes: CAD data of existing structures in original photograph; CAD data of proposed action; location, pitch, yaw, roll and lens of camera; and locations of hard match points throughout the foreground, middleground or background of the image. A large number of match points are not required in these conditions since camera position using this technology is fairly reliable and accurate.

When to use either form of data acquisition will depend on the data one is able to acquire, the number of naturally existing match-points in the potential viewpoint, and the degree of difficulty of adding additional match-points (floating balloons, adding objects of known heights to foreground or background, etc.)

From my own personal experience in highly urban settings like Manhattan, the camera match function has worked well because of the relative ease in obtaining optimal match points when accurate 3D CAD models of the surroundings are available.