Integration of Motion Capture with CAD for Camera Placement

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Abstract
Positioning motion capture cameras for a study using a vehicle mockup is complicated due to the large amount of obstructions caused by the vehicle, the test subject’s body, as well as the potential complexity of the subject’s motion. In the past, a trial and error method has been used for camera positioning. Cameras are positioned, calibrated and then the motion of a fully markered subject is observed. Data is collected and reviewed to ensure that markers are visible throughout the motion. Adjustments are then made to camera positions and the process is repeated. A tool for streamlining this process has been developed at Ford. It uses a hardware-in-the-loop system including a programmable vehicle buck called the Human Occupant Package Simulator (HOPS) and its virtual representation in a CATIA CAD model (VHOPS). All Vicon motion capture cameras integrated with HOPS are virtually created in VHOPS and matched to their physical setting. With this method, the camera placement is accurately assessed and potential obstructions can be easily detected. This tool makes it possible to achieve optimal camera positioning for various studies and therefore improve marker visibility while greatly decreasing the time it takes to set up motion capture cameras.

Keywords: Motion capture, CAD, Camera placement

1. Introduction
Recently, motion capture has been widely used in the auto industry to study vehicle ergonomics for better vehicle design. Mockup structures are often built to represent a vehicle environment in which the interaction between an occupant and the vehicle is investigated. Positioning motion capture cameras for a study in this environment becomes complicated due to the large amount of obstructions caused by the mockup component, as well as the test subject’s body. It is more difficult to place and orient cameras for complicated motions with large ranges of movement, such as ingress/egress. In the past, a trial and error method has been used. Cameras are positioned, calibrated and then the motion of a fully markered subject is observed. Data is collected and reviewed to ensure that markers are visible throughout the motion. Adjustments are then made to camera positions and the process is repeated. It is very tedious and time consuming. To improve this, a tool for streamlining this process has been developed at Ford.

2. HOPS and Virtual HOPS
Human Occupant Package Simulator (HOPS) is a quarter programmable vehicle buck used at Ford to represent driver or second and third row passenger compartments for motion capture tests. It is capable of simulating vehicle packages with a wide range of dimensions. Up to fourteen Vicon cameras are integrated in HOPS to capture an occupant’s motion. HOPS is part of a hardware-in-the-loop system that connects the vehicle package to its virtual representation in a CATIA CAD environment named Virtual HOPS (VHOPS). Any changes in HOPS are accurately represented in VHOPS, allowing a perfect match between the real world hardware and the virtual world in CAD. Figure 1 shows a HOPS setup representing a vehicle’s 1st row package, where the Vicon system is used to capture a fully markered subject in a seated posture.

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Figure 1: Motion Capture using Human Occupant Package Simulator (HOPS)

Shown in Figure 2 is the virtual representation of the same vehicle package in VHOPS. The digital manikin in CATIA is scaled to the same anthropometry of the subject in the same seated posture.

Figure 2: Virtual HOPS with a Digital Manikin

In addition to the package components, all Vicon motion capture cameras integrated with HOPS are also parametrically modeled in VHOPS. Their position and orientation are controlled according to the position and orientation of the physical cameras.

3. Camera Modeling in CATIA

The viewing volume that can be seen by a motion capture camera is represented as a pyramid with its tip located at the center of camera sensor. The position and orientation of the pyramid is determined by both the camera sensor center and the orientation of camera sensor plane. The size of the pyramid is determined by the Angle of View (AOV) of the camera.

To model the sensor plane of the pyramid, three vectors need to be determined: 1) normal vector of the sensor plane, 2) the horizontal axis in the sensor plane, and 3) the vertical axis in the sensor plane, as illustrated in Figure 3.

Figure 3: Camera sensor plane orientation

The orientation of the camera sensor plane is expressed in the format of quaternion:

$$Q = (w, x, y, z)$$  \hspace{1cm} (1)

The three vectors can be calculated using the following equations,

$$V_{\text{normal}} = (2xz + 2wy, 2yz - 2wx, 1 - 2x^2 - 2y^2)$$  \hspace{1cm} (2)

$$V_{\text{horizontal}} = (1 - 2y^2 - 2z^2, 2xy + 2wz, 2xz - 2wy)$$  \hspace{1cm} (3)

$$V_{\text{vertical}} = (2xy - 2wz, 1 - 2x^2 - 2z^2, 2yz + 2wx)$$  \hspace{1cm} (4)

The AOV includes horizontal AOV and vertical AOV, which are calculated from the sensor size and focal length of the lens using the following formulas,

$$\text{AOV}_h = 2 \tan^{-1} \left( \frac{h}{2f} \right)$$  \hspace{1cm} (5)

$$\text{AOV}_v = 2 \tan^{-1} \left( \frac{v}{2f} \right)$$  \hspace{1cm} (6)
where,

- $AOV_h$: horizontal angle of view
- $AOV_v$: vertical angle of view
- $f$: focal length of the lens
- $h$: horizontal width of sensor
- $v$: vertical height of sensor

Four rays are created to form the parametric viewing pyramid. The first two rays are created in the plane defined by the sensor plane’s normal vector and vertical axis, one starting from sensor center and forming angles of $AOV_v$ above the normal vector and the other below the normal vector with the same angle. Similarly, the third and fourth rays are created in the plane defined by the sensor plane’s normal vector and horizontal axis, starting from sensor center one forming angles of $AOV_v$ to the left of the normal vector and the other to the right of the normal vector. The viewing pyramid surfaces are then generated using these four rays. Figure 4 depicts the parametric viewing pyramid and the rays along the vertical $AOV$.

4. Camera Coverage Representation

All cameras mounted in HOPS are modeled and integrated with other VHOPS components. To obtain the position and orientation of these cameras, a data file containing the information is exported from the Vicon system in XML compatible format. Figure 5 shows an example of the file.

The XML file includes the following data:

- camera ID
- sensor size
- camera position: in $(x, y, z)$
- camera orientation: in quaternion $(w, x, y, z)$
- focal length

This XML file is then imported into VHOPS and the above data is extracted. Each camera is identified based on camera ID and the sensor plane in the parametric viewing pyramid is reoriented based on the camera position and orientation quaternion using equations (2) – (4). AOVs are calculated based on sensor size and focal length using equations (5) and (6). All camera models in VHOPS are adjusted to their physical setting, and their viewing volumes are updated in CATIA, along with the virtual package components (Figure 6).
any physical structure of the HOPS indicates potential obstructions.

VHOPS also uses digital human manikins that are scaled to subjects of various heights and weights. The manikins are strategically positioned in the VHOPS based on the type of tasks and used to determine whether the setup of the cameras will see the markers on various sizes of manikins as their bodies are in these strategic positions.

Setting up cameras to capture both extremely short and tall subjects has always been a challenging task. Multiple trials with real subjects are often needed. This method eliminated the need for real time trials. Figure 7 shows a short female manikin (orange) and a tall male (blue) manikin entering a vehicle. In this particular case, there is no intersection between the boundary of camera viewing volume and the manikins, indicating that a good camera setup is achieved. When intersections are detected, the cameras can be quickly adjusted and rechecked, thus ensuring the coverage of subjects with extreme statures.

Similarly, motion strategy may also affect the visibility of markers, especially during ingress/egress. For ingress, as an example, there are three typical strategies, as depicted in Figure 8: 1) leg first (green), 2) head first (blue), and 3) buttock first (orange). With this new method, the camera positions can be easily checked against the postures in these strategies to make sure markers are visible for all strategies.

Furthermore, previously collected motions in a similar vehicle environment can be used as a reference within VHOPS with the camera viewing volumes. Markers from a captured motion can be imported into VHOPS and the corresponding digital manikin can be set to various key postures of the actual motion. The entire motion can be checked to determine if the cameras are able to see all the markers throughout the motion. This is extremely useful for a complicated motion such as ingress/egress when a subject’s body undergoes a wide range of movement. Since the motion had been captured using mocap, it is realistic and provides an accurate assessment of marker blockage from cameras. Figure 9 shows several key postures during a manikin’s ingress movement, with the viewing volume of the cameras showing the coverage of the manikin’s body during the entire ingress motion.
5. Application

The camera placement method has been used in several motion capturing tests. The following example shows the case for a 2nd row ingress/egress test, which covered various configurations involving different ground to Seating Reference Point (SgRP) height (or SAE dimension H5-2) and door opening height – roof rail to SgRP height (or SAE dimension H11-2). Since the experiment covers a large range of these dimensions, the camera setting that works for one configuration may not work for another configuration.

Comparing Figure 10 and Figure 11, one can see that the same camera sees different portion of a tall subject in the configurations with different ground height. With a lower ground height, most of the markers (red points) on the subject’s head are covered by the camera’s viewing volume, while with a higher ground height, the markers on the head are outside of the top boundary of the camera’s viewing volume. The camera needs to be rotated upward to accommodate both cases.

Another application is checking the blockage generated by vehicle components. As shown in Figure 10, the roof rail of the door opening may block the head’s markers in an SUV-type vehicle configuration with a low ground height and large door opening. Figure 12 shows another example of an ingress motion with the door at a parking lot position. The door frame mockup structure could potentially block the side camera view of the markers on the subject. One way of checking the blockage is creating a section passing through the center of camera and the viewing volume. Figure 13 shows the resultant section, which indicates the section of door frame and map pocket mockup are in the line of the manikin section and may block the markers on the foot and shoulder. Based on these results, the blocked camera is repositioned and the door mockup is redesigned to reduce the blocking area.
Conclusion

This integration of camera CAD models with the Ford VHOPS provides a tool to assess the camera placement and marker blockage quantitatively. It enables a faster and more accurate adjustment to the camera position and orientation, and makes it possible to achieve optimal camera placement for various studies. It improves marker visibility while decreasing the time it takes to set up motion capture cameras. The system also allows for virtual tryout of various vehicle packages with a manikin in targeted postures in VHOPS. This ensures that the resultant cameras’ views are able to fully cover all test conditions.

References
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