FAB verses tradition camera-based motion capture systems

The advent of micromachined inertial sensors, such as rate gyroscopes and accelerometers, has made new navigation and tracking technologies possible. These sensors, coupled with advanced multisensory fusion techniques, have been integrated to create the FAB system—a completely wireless and camera free system for the tracking of human motion. In this document, we will briefly compare and contrast FAB with traditional camera-based systems.

The FAB system.

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Camera-Based Motion Capture

Camera-based motion capture systems are the industry standard for tracking human motion. A typical system consists or a network of cameras, 8 being typical, which enclose the workspace. The subject to be tracked is outfitted with reflective markers and moves within the workspace. The camera images of the reflective markers are used to triangulate the 3-D position of the reflective markers. The orientation of each human body segment is inferred based on the position of three markers.

Accuracy

Although the positional accuracy of the system depends on details such as the number of cameras used and the size of the workplace, it is typical to achieve root mean square residuals less than 1 mm. The angular accuracy of measuring the orientation of a particular body segment depends on the distance between the markers, but 0.2 degree accuracy for arm and leg segments is easily obtainable. With a camera-based system it is possible to determine both the angular orientation of the subject's body segments, as well as the subject's position within the workspace.

The previous description of accuracy is a measure of how well the system can resolve the position of the markers. However, the user is usually concerned with resolving the position of the underlying skeletal structure. The twisting and movement of the skin relative to the bones also adds error in the estimate of subject position and depends on the way the markers are attached to the skin and the rapidity of the motion.

Frame rate

Camera-based systems often capture data between 100 Hz and 400 Hz; however, systems exists which can log data faster than 2000 Hz. A trade-off exists between the frame rate and the accuracy with which the position of the markers can be resolved (higher frame rates yield less accurate positional data).

Flexibility

Since the system simply tracks the position of spherical markers, it is very flexible. More markers can be placed on the region of interest, for example the human back, and the user can monitor the motion of as many points as desired. In fact, because only the position of optical markers are tracked, the system is well-equipped to track even animals or inanimate objects. The cost of this flexibility is, of course, that it is not targeted for a specific model of the human body. Converting the positional data for each markers into the angles and position of the avatar requires additional mathematics that depend on the location of the markers.

Dynamics

Determining human dynamical quantities such as joint forces and torques require knowledge of the velocities and acceleration of the joint segments. Because camera-based systems track the position of optical markers, determining velocity and acceleration requires taking the time derivative of the camera data once and twice respectively. Noise in the position data is highly amplified during derivative operations, resulting in noisy acceleration estimates and thus inaccurate force and torque calculations.

Occlusion and marker mismatch

Perhaps the most frustrating aspect of camera-based motion capture systems is marker occlusion and mismatch. Occlusion occurs when one of the markers is hidden from the cameras. If the cameras cannot see the marker, then its positional information is lost. This can be partly remedied by using redundant markers, but the problem is still a serious one.

Although each marker looks the same to the cameras, the system, to a certain extent, is able to uniquely identify each marker. The camera system predicts the position of marker X for the next frame, and then identifies the marker closest to this predicted position as marker X. There are limitations to how well this technique works and it is very likely that during a motion capture of even a few seconds, that the system will confuse several markers. When this happens, the mismatches must be resolved by the user. This can be a time consuming process.

Calibration

Calibration with a camera-based system involves moving a wand covered in optical markers through the workspace. No calibration of the subject to be tracked is required since the system tracks only the position of the reflective balls. Nevertheless, camera calibration takes about 15 minutes to complete.

Cost

The cost of a camera-based system depends, of course, on the number of cameras purchased as well as their resolution. A typically 8 camera system costs approximately $150,000 US.

Pros and cons of camera-based motion capture

Pros

Good accuracy

Position as well as orientation information is

available

Flexible

Cons

Limited workspace

Time consuming calibration

Not tailored to human model
(slow animation times)

Marker occlusion and mismatch

Poor resolution of dynamical quantities

Markers move with skin relative to underlying skeletal structure

Cost

FAB motion capture

The FAB system consists of a network of sensors attached to the patient. Each sensor measures its three dimensional orientation in space as well as acceleration. Unlike camera-based techniques where three markers are required for each body segment, with FAB only a single sensor is required. FAB captures motions by a method entirely different than camera-based systems. Each sensor contains magnetometers, accelerometers and gyroscopes. The sensors use the magnetometers to determine where north is and the accelerometers to determine where down is. The gyroscopes indicate how quickly the sensors are turning and twisting. By fusing all of this information together, the sensors are able to determine their orientation in space, as well as their acceleration, to a high degree of accuracy.

Accuracy

Although accuracy depends on the rapidity of the motion as well as the quality of the local magnetic field, typical accuracies are better than 1 degree for angles in vertical planes and 3 for angles in the horizontal plane.

The FAB sensors can shift with the skin relative to the underlying skeletal structure. Although this is a problem that plagues any external-marker-based system, the shifting is more pronounced with the FAB sensors than the optical markers because the optical markers can be spread out further along the body segments.

Sampling rate

The FAB system samples its internal sensors at 100 Hz. Although this is less than most camera-based systems, the fact that both acceleration and angular velocity information are measured directly means that 100 Hz FAB data contains vastly more high-frequency information than 100 Hz camera data. The FAB data is compressed down to 25 Hz and transmitted wirelessly to the receiver. The data represents the orientation and acceleration of the sensor modules, containing a clean estimate of all frequencies components up to the Nyquist frequency of 12.5 Hz. Components of the motion with frequencies greater than 12.5 Hz are removed. The motion of the subject can be rebuilt to whatever frame rate is desired; however the rebuilt signal will contain no frequencies greater than 12.5 Hz. We have found the resulting animation from the FAB systems is noticeable smoother and more life-like than camera-based animations.

Tailored to a human model

The FAB system is specifically tailored for a particular human model with a set number of degrees of freedom. This makes animation a seamless process; in fact, human motion can be captured and animated in real time. The disadvantage is that adding additional degrees of freedom or animating something other than a human require changes in the software.

Dynamics

Because FAB measures orientation as well as acceleration, it is well suited for calculating biomechanical quantities such as joint forces and torques. Because minimal time derivatives of sensor data are required, the force estimates are clean, in contrast to the noisy estimates from camera-based systems.

Occlusion and marker mismatch

Because the FAB sensors determine their orientation based on measurements of earth's magnetic and gravitational fields, occlusion of these fields is not possible. However, magnetic fields from nearby ferrous metal and magnetic objects distort the field from earth and limit the accuracy of angles measured in the horizontal plane.

Marker mismatch is not possible with FAB.

Calibration

Calibration is a simple process where the subject stands in a predefined "neutral" position. Calibration takes 20 seconds.

Cost

A standard FAB system costs under $40,000 CAN.

Pros and cons of FAB motion capture

Pros

Unlimited workspace

Excellent angular accuracy in vertical planes

Captures subject orientation as well as acceleration

Fast animation of human models (highly tailored)

Marker occlusion or mismatch is not possible

Fast, simple calibration process

Good resolution of human dynamics

Cost

Cons

Cartesian positional information is difficult to achieve

Angles measured in the horizontal plane are subject to errors from magnetic distortion

Sensors move with skin relative to underlying skeletal structure

Comparison table

	Camera-Based System	FAB System
Range Restrictions	Confined to area enclosed by cameras	None
Markers	System tracks Cartesion coordinates of optical markers	System tracks 3D orientation of sensor modules and sensor acceleration
Flexibility	Any number of reflective markers can be used	Adding additional sensors requires changes to FAB's underlying software
Animation Time	1 hour to several days	Possible in real time
Accuracy	0.2 for arm and leg segments	1.0 for angles measured in vertical plane 0.3 for angles measured in horizontal plane
Sampling Rate	Up to 2000Hz (100 - 400Hz typical)	100Hz, however velocities and acceleration are measured directly
Accuracy Limited by	Marker occlusion and mismatch	Distortion of magnetic fields
Human Dynamics	Poor resolution	Excellent resolution
Calibration Time	15 minutes	20 seconds
Costs	$150,000 US	Less than $40,000 US