# MoCap – The Advantages of Accelerometers and Accuracy Improvement

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***Abstract*****—**Using MEMS accelerometers in MoCap systems offers great advantages over the other systems. One must know that no system is perfect and every one of them is good for acertain project. Improving the accuracy of measurement with accelerometers is an important factor for high quality and real-time animation.

***Keywords*****—** mocap, motion capturing, error, animation, dsp, recording, accuracy, improve,accelerometers, MEMS

## I.INTRODUCTION

In the last 20 years the popularity of Motion Capturing ( MoCap ) technique in animation has increased rapidly. MoCap system in animation refers to recording the movements of an actor and then using that information to animate digital character models in 2D or 3D computer animation. MoCap gives some great opportunities to animators such as timesaving, simplifying the process of animation and others.MoCap can be applied in many other fields: sport (analyzing movements), military, robotics, game industry, medicine and others. This report is focused on using accelerometers in MoCap computer animation.

## II. MOCAP PARAMETERS AND COMPARISON OF TYPES

There are many MoCap techniques, but three of them have practical application in animation industry – MoCap with markers, MoCap with magnetic sensors and MoCap with accelerometers. The next paragraph reveals the most important parameters of the MoCap system and using these parameters a table of system comparison is build - Table.1. The important parameters of Mocap systems are:

- Accuracy: the error of measuring the movements of the actor. This is a basic problem to solve.
- Animation in real-time: the possibility of computer model to follow the actor’s movements with a very short ( negligible ) time delay.Then the actor could experiment with different movements and make corrections.
- Freedom of movements: The freedom of actor movements (acting) gives an opportunity for rich and interesting animation.
- Frames per second: the recording speed. The greater the speed the better the system will capture fast movements like running, jumping, waving etc.
- Interruptions: recording themovemantwith no interuption in the process.
- Identification: the ability of the system to recognize body parts.
- External influence: the independence of the system from external influence like magnetic fields or light.
- Price: the less the better. As one can guess the goal is to make high quality MoCap system with affordable price.
- Training: training the actors to work with the system.
- Portability: the ability of the system to be moved.
- Software complexity: the complexity of the softwaredeveloped for data analyzing and character animating

The three basic MoCap systems are :

**MoCap with markers**. Markers are fixed to the face and the body of the actor. Then the actor is shot by cameras. After that software analyzes the position of the markers in each frame and calculates the movement of each part of the body. After that the data is sent to the animating software. The markers could be made in different shape and fixed on differentplaces on the body depending on the software and the algorithm for analyzing the movements. For identification of the markers they are made in different colors. For better detection they are made from fluorescent, light reflecting material or LED. LEDs are easily detected and could be modulated for identification

**MoCap with accelerometers**. Accelerometer devices are fixed on the body of the actor. Then information about angles of position of the parts of the body is taken from the devices.

TABLEI. COMPARISON OF ADVANTAGES AND DISADVANTAGES OF MOCAP SYSTEMS

| **MOCAP WITH MARKERS** | |
|---|---|
| **Advantages** | **Disadvantages** |
| **High accuracy** | **High Price** |
| **High recording speed** | **Recording interruption** |
| **Actors movement freedom** | **Complicated software** |
| **Real-time** | **Not portable** |
| **Face expressions recording** | **Great amount of high-res cameras** |
| **Position indication** | |
| **Most popular** | |
| **Many applications** | |
| **MAGNETIC FIELD MOCAP** | |
| **Advantages** | **Disadvantages** |
| **High accuracy** | **Limited movement freedom** |
| **Gives orientation and position data** | **Externalinterfere** |
| **Low price** | **Low recording speed** |
| **Simple software** | **Noise** |
| **6DOF** | |
| **No occlusion** | |
| **Sensor Identification** | |
| **MOCAP WITH ACCELEROMETERS** | |
| **Advantages** | **Disadvantages** |
| **High accuracy** | **No position data** |
| **Real time** | |
| **Affordable price** | |
| **Simple software** | |
| **High recording speed** | |
| **Sensor identification** | |
| **6DOF** | |
| **Portability** | |
| **No occlusions** | |
| **Independence from magnetic fields and light sources** | |

Comparing the systems it is obvious why there is a growing popularity of the MoCap with accelerometers.

## III.MOCAP WITH ACCELEROMETERS – ACCURACY IMPROVEMENT

The goal of this section is to show a new approach for improving accuracy of MoCap with accelerometers by combination of classical solutions and new ideas.

First the construction and principals of work of MEMS (Micro – Electro - Mechanical Systems) accelerometer will be explainedbriefly. Second the main problems causing errors will be revealed and then the solutions of these problems will be considered.

In Fig.1 [8] a simplified construction of MEMS accelerometer is shown.

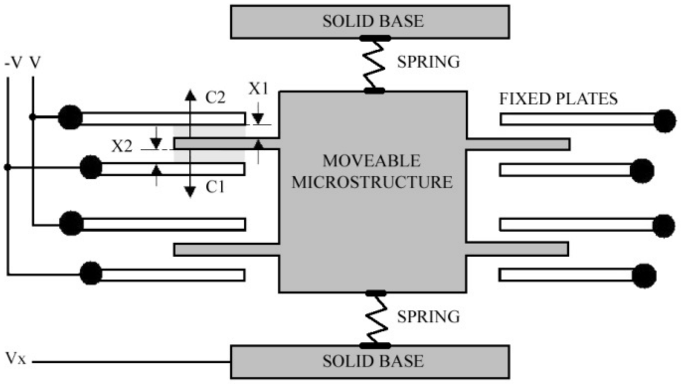

Fig.1.**Simplified scheme of MEMS accelerometer**

If the accelerometer changes inclination or its moved in space the moveable microstructure also moves. When the moveable microstructure changes its position( distances X1 and X2 ) the capacitance C1 and C2 between the fixed plates and the moveable microstructurechanges.Measuring the difference of C1 and C2 gives the acceleration or the angle of inclination.

The main problem in every measurement system is the accuracy. Accuracy in MoCap with accelerometers depends on the following factors:

- Brownian noise-Mechanical noise due to the Brownian motionof the proof mass [7].
- kT/C noise - A major noise source in switched-capacitor circuits, generated by the thermal noisesampling of the switches [7].
- Temperature dependence – The output of the accelerometer varies with temperature.
- Amplifier noise - The readout circuitry uses correlated doublesampling to cancel the input CMOS amplifier flickernoise. This noise is amplified by the ratio of total input capacitors (including the parasitic) to the integratingcapacitor [7], [9].

-Quantizier noise - Quantization noise is related by theresolution of ADC. As the resolution is increased,quantization noise decreases [7].

- Gimbal lock - Gimbal lock is defined as the loss of one degree of freedom which occurs when the axes of twoof the three gimbals needed to apply or compensate for rotations in three dimensional spaces aredriven to the same direction [10].
- Tilt Sensitivity – The sensor is mostresponsive to changes in tilt when the sensitive axis is perpendicular to the force of gravity and isleast responsive to changes in tilt when the sensitive axis is oriented in +g or –g position [10].
- Non-linearity - Non-Linearity is the deviation of the sensor output signal from a theoreticalstraight line which has been fitted to the data points of an actual calibration [10].
- Hysteresis - Hysteresis is the difference in sensor output signal at a specific input when applied in the increasing and then decreasing sectors of a single cycle of short time duration at constant temperature [10].
- Tremor detection –With relatively small dynamic motions such as in human tremors, the magnitude of the

accelerations due to dynamics may be of the same relative size as those due to small changes in the orientation of the sensitive axis, by coupling to Earth's gravity.

- Package Alignment Error is the angle between the accelerometer-sensing axes and the referenced package feature. The units for package alignment error are "degrees." Packaging technology typically aligns to within about 1° of the package.
- Ratiometric error - As the supply voltage varies the output voltages of the accelerometers scale proportionately [10].
- Transverse sensitivity - Transverse Sensitivity is the sensitivity to input in the nonsensitive,cross-axis direction, and it is a potential source of measurement error in a user'sapplication.
- Dampingratio-Dimensionless measure describing how oscillations in a system decay.
- Mounted resonant frequency - Mounted resonant frequency is the point in frequency in the accelerometer's frequency response wherethe accelerometer outputs maximum sensitivity [12].
- Sliding - The sensors are sliding over the skin[4] - The alignment with the bones can change due to relative movements of muscles and skin. This misalignment can result in large errors of angles.

Methods for solving the accuracy problems of MoCap system with accelerometers will be shown and explained:

- Brownian noise– Kalman filter is used against Brownian noise. Kalman Filter is a digital filter used to filter noise on aseries of measurements observed over a time interval [13], [7].Most systems can not be perfectlymodeled and that noise distributions are hardly known accurately often sets the limits for the achievedperformance. However, even when the actual conditionsare far from those assumed, the Kalman filter can often be stabilized and fine tuned. Principle scheme is shown on Fig.2 [14].

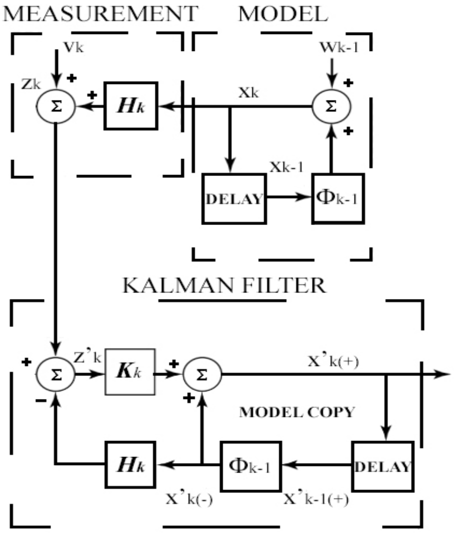

Fig.2.**Kalman Filter – Block Diagram**

The equations 1 and 2 represent how the system is modeled:

$$\mathrm{x}_{\mathrm{k}} = \Phi_{\mathrm{k}-1}\mathrm{x}_{\mathrm{k}-1} + \mathrm{w}_{\mathrm{k}-1} \tag{1}$$

$$wk = N(0, Qk) \tag{2}$$

In equations 1 and 2 Φ is the state transitionmatrix, x is the signal, w is Gaussian noise.

Kalman Gain is expressed in equation 3:

$$\mathrm{K}_{\mathrm{k}} = \mathrm{P}_k(-)\mathrm{H}_k^T[\mathrm{H}_k\mathrm{P}_k(-)\mathrm{H}_k^T + \mathrm{R}_k]^{-1} \tag{3}$$

In equation 3 H is the measurement sensitivity and P is error covariance extrapolation.

The prediction equation is 4:

$$x'_k \Phi = x_k (_{k-1}) + \tag{4}$$

- Temperature dependence –The output from the accelerometer varies with temperature. An accelerometer may have an offset that varies by 1 - 2.4mg/°C and a sensitivity that varies by 0.032%/°C. Choosing an accelerometer with small output variations overtemperature is a key to maintaining low errors [11]. The bright side of this problem is that the accelerometer is placed on human body and so the temperature is relatively stable – 36.5 ÷ 37.5 °C. Further correction can be made with temperature compensation using the accelerometer temperature characteristics and look-up table or formula.

-Quantizier noise - The effective quantization noise is related by theresolution of ADC. As the resolution is increased,quantization noise decreases. Thus, quantization noisecan be reduced, if not totally eliminated.

- Gimbal lock –In MoCap systems Euler Rotations is used to describe the movements. A disadvantage of this method is loosing a degree of freedom. The coordinate system is shown on Fig.3.

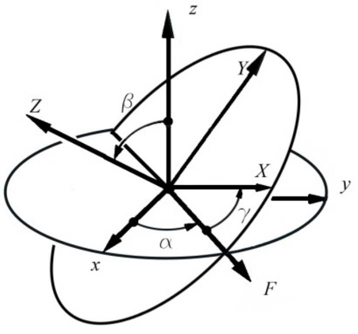

Fig.3.**Euler Rotation System**

The rotation is expressed by:

$$[R] = \begin{bmatrix} c_\alpha c_\gamma - s_\alpha c_\beta s_\gamma & -c_\alpha s_\gamma - s_\alpha c_\beta c_\gamma & s_\beta s_\alpha \\ s_\alpha c_\gamma + c_\alpha c_\beta s_\gamma & -s_\alpha s_\gamma + s_\alpha c_\beta c_\gamma & -s_\beta c_\alpha \\ s_\beta s_\gamma & s_\beta c_\gamma & c_\beta \end{bmatrix} \tag{5}$$

If β=0 the rotation is:

$$[R] = \begin{bmatrix} c_\alpha c_\gamma - s_\alpha c_\beta s_\gamma & -c_\alpha s_\gamma - s_\alpha c_\beta c_\gamma & 0 \\ s_\alpha c_\gamma + c_\alpha c_\beta s_\gamma & -s_\alpha s_\gamma + s_\alpha c_\beta c_\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$[R] = \begin{bmatrix} \cos(\alpha+\gamma) & -\sin(\alpha+\gamma) & 0 \\ \sin(\alpha+\gamma) & \cos(\alpha+\gamma) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{7}$$

As can be seen from equation 7 when changing a and γthe rotation axis remain in Z direction. The last column and line stay the same – a degree of freedom is lost.

The best way to avoid the gimbal lock is to acquire quaternions for representing rotations in 3Dspace [16]. The quaternion can be described as:

$$q = [q_1 \;\; q_2 \;\; q_3 \;\; q_4]^T \qquad (8)$$

$$|q|^2 = q_1^2 \;\; q_2^2 \;\; q_3^2 \;\; q_4^2 = 1$$

Quaternion can be associated with a rotation around axis:

$$q_0 = \cos(\alpha / 2)$$

$$q_1 = \sin(\alpha / 2)\cos(\beta_x) \qquad (9)$$

$$q_2 = \sin(\alpha / 2)\cos(\beta_y)$$

$$q_3 = \sin(\alpha / 2)\cos(\beta_z)$$

- Tilt Sensitivity–If one axis (X-axis) is used to calculate the tilted angle of the accelerometer the following trigonometric relationship is used:

$$\mathrm{V_{outx}} = \mathrm{V_{off}} + \mathrm{S}(\sin\Theta) \qquad (10)$$

Where Voutx is the output voltage from the X-axis of the accelerometer, Voff is the offset voltage, and S is the sensitivity of the accelerometer. The acceleration output on the Xaxisdue to the gravity is:

$$\mathrm{A}_x = \frac{\mathrm{V_{outx}} - \mathrm{V_{off}}}{S} \qquad (11)$$

Therefore, the angle of tilt becomes thefollowing:

$$\Theta = \sin^{-1}(\mathrm{A}_x) \qquad (12)$$

From this relationships a graphic of sensitivity vs. tilt angle can be made – Fig.4

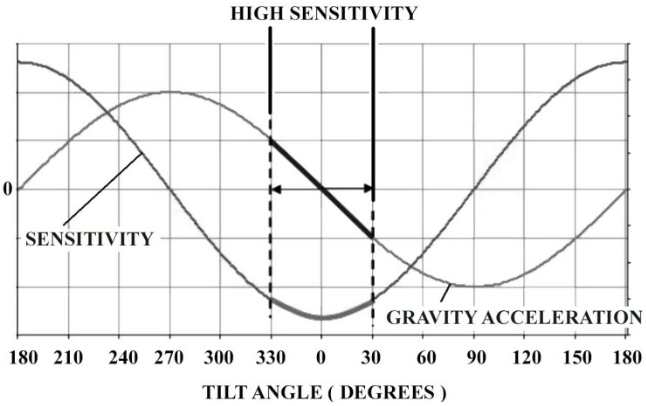

Fig.4.**Sensitivity – Tilt relationship**

The sensitivity diminishes between -90° and 45° and between +45° to +90°. To solve this problem 2 or 3 axes accelerometer must be used. Because of 90 degree difference of axes position when the sensitivity of X is maximum the sensitivity of Y is minimum and vise versa. Therefore, maximum tilt sensitivity can be maintained if both the X and Y outputsare combined [10].

- Non-linearity - Non-linearity is defined as the maximum deviation of the output response from abest fit line expressed in a percentage of Full Scale Output – Fig.4 [11].

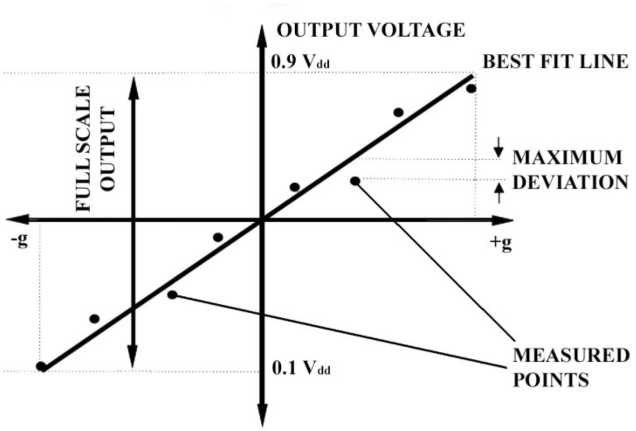

Fig.5.**Non-linearity**

When the application requires measurements of around the 0 g condition (as withtilt measurement), the non-linearity effect is negligible and can be ignored.

- Hysteresis – Before measuring a hysteresis test should be made. The test is showing the difference between tilt output when changing the tilt of the accelerometer form 0 to 360 degrees in two opposite directions. A table of differences is then used to minimize the error form hysteresis.
- Tremor detection - Unless a tremor is restricted to a perfect straight line, the orientation input for just a few degrees of rotation will mask the true dynamics of the tremor. Detecting tremors is possible by using more than one accelerometers.
- Output Data Rate -The rate at which data is sampled. Bandwidth is the highest frequency signal thatcan be sampled without aliasing by the specified Output Data Rate. Data Rate can cause error if Nyquist sampling rule is not applied - bandwidth is half the Output Data Rate.
- Package Alignment Error – This error can be easily corrected with calibration.
- Ratiometric error - Good voltage regulation is essential to reduce the source of this error. To compensate the error a power supply monitoring should be applied. The correction is made by using the monitoring data, specification data and experimental data.
- Transverse sensitivity - The Transverse Sensitivity of a sensor refers to any output caused by motion, which is not in the same axis that the sensor is designed to measure. A high-quality accelerometer will have typical transverse sensitivity values from 3% to 5%. Values of as low as 1% are also available on some models. Using 3 axial accelerometer reduces significantly the problem by comparing the data from the axes.
- Sliding – Sliding cannot be avoided. The only way to correct this error is by compareing data from different accelerometers placed on the same part of the body. By experimental work a table of disposition can be made and used to correct the data.Knowledge about muscle movement can be used to make a decision how to correct the data. The accelerometers should be placed as closer to the bone as possible.

Adding the errors may be a tricky thing. At first one might think that the error in Z = A+ B would be just the sum of the errors in A and B:

$$(A+ \Delta A) + (B + \Delta B) = (A+ B) + (\Delta A+ \Delta B) \tag{13}$$

This will happen only if A and B have the same sign and maximum magnitude. Better way to calculate the error is to think of A and B as perpendiculars:

$$(A \pm \Delta A) + (B \pm \Delta B) = (A + B) \pm \sqrt{\Delta A^2 + \Delta B^2} \tag{14}$$

Further analysis of the movement can be made. Using the knowledge of natural movements of human body can help to separate the unnatural movements. The analysis can be made by statistic, comparingmathematical models or Fourier analyses ( DFT ). If there is (for example) a spectral component in DFT that is unnatural itcan be removed and then by IDFT the new ( natural ) movementcan be synthesized.

The calibration of anaccelerometer is a key technique to improve the accuracy. There are many different techniques for calibration. A two point acceleration calibration can be performed toaccurately determine the sensitivity and correct the offsetcalibration errors.

Reducing the noise on the accelerometer outputs can be done through low passfiltering. There are a great many different types of filter circuits (Butterworth, Chebyshev, and Bessel, to name a few).

## IV.CONCLUSION

As can be seen from this information the MoCap system with accelerometersoffers great advantages over the other systems. The combination of error corrections and further movement analyses offer MoCap with high enough accuracy ataffordable price.

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