Kinematics Extraction of the ATD Head Impact Component Tester from Angular Rate Sensor and Accelerometer Data

Robert D. Huculak[1], Jefferson D. Vieira[1,2] and Hamid M. Lankarani[2]

[1] *National Institute for Aviation Research, Wichita State University, rhuculak@niar.wichita.edu*
[2] *Department of Mechanical Engineering, Wichita State University, hamid.lankarani@wichita.edu*

In aerospace seat development and certification testing, Anthropomorphic Test Device (ATD) kinematics, particularly head trajectory, can be difficult to evaluate. Most commonly, ATD kinematics are determined through photometric analysis from high-speed video of the dynamic impact test. Correction methods for parallax, perspective, depth, and scale factor through calibration of a camera sensor, lens, and focus setting combination have seen improvements recently. While these improvements have increased accuracy and efficiency in post-processing the kinematics, the major fault of photometric analysis still remains target visibility. The target, or object of interest, must remain in view of the high-speed camera. In aerospace seat testing, inherent test setup requirements lead to many instances resulting in loss of target visibility mainly due to ATD arm and leg flail in forward facing seats and large head rotation in side and aft facing seats. Another option to evaluate Head Impact Criteria is utilizing a Head Component Tester (HCT), Figure 1. The HCT, designed based on multibody modeling and simulation, is composed of a Hybrid II 50th head and neck assembly mounted on an inverted pendulum; a nitrogen accumulator applies pressure to a pneumatic piston to accelerate the pendulum system. Using the HCT, it is not always practical to provide a thorough setup to perform a photometric analysis, thus, another method to evaluate ATD kinematics from accelerometer and angular rate sensor data can be beneficial.

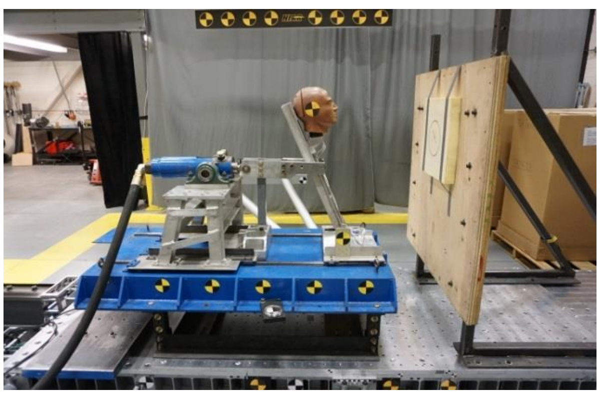

Fig. 1: Head Component Tester

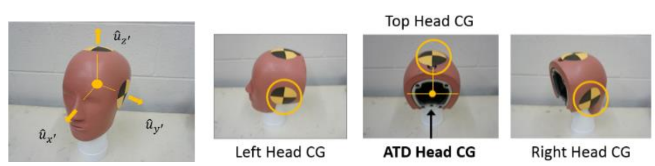

Fig. 2: Head unit vectors and auxillary tracking locations

Starting with a component level test device, with a known displacement, the influence of head contact on the acceleration and angular rate sensor data is evaluated. The effect of the contact is determined from the difference between the calculated head displacement and the known trajectory along with photometric analysis data. Additionally, using rigid body mechanics, the location of other points on the ATD head (left, top, and right head CG), Figure 2, are calculated and compared to photometric data. The initial auxiliary ATD head CG locations (left, top, and right) are evaluated from the initial head position, and the initial transformation matrix $\underline{A}_0$, obtained as

$$\underline{A}_0 = [\hat{u}_{x'}, \hat{u}_{y'}, \hat{u}_{z'}] \tag{1}$$

where:

$$\underline{r}_{CG} = \frac{\underline{r}_L + \underline{r}_R}{2}, \quad \hat{u}_{y'} = \frac{\underline{r}_L - \underline{r}_R}{\sqrt{\left(\underline{r}_L - \underline{r}_R\right)^T \left(\underline{r}_L - \underline{r}_R\right)}}, \quad \hat{u}_{z'} = \frac{\underline{r}_T - \underline{r}_{CG}}{\sqrt{\left(\underline{r}_T - \underline{r}_{CG}\right)^T \left(\underline{r}_T - \underline{r}_{CG}\right)}}, \quad \hat{u}_{x'} = \hat{u}_{y'} \times \hat{u}_{z'} \tag{2}$$

The measurement of linear acceleration and angular velocity, from angular rate sensors, in the local frame (i.e. ATD head CG) can be used to determine the ATD kinematics with six degrees of freedom (6 DOF) in the global frame [1-4]. Using rigid body kinematics principles, the local accelerations and angular velocities can be transformed to provide global acceleration, global velocity, and global displacement. In this study, this is accomplished by generating the transformation matrix $\underline{A}$, in terms of Euler parameters $\underline{p}$, relating the local frame to the global frame. The four Euler parameters $\underline{p}$ describe the rotation of an object in three-dimensional space through a single rotation ϕ about a vector $\underline{u}$, the orientational axis of rotation, as shown in Figure 3. The rate of change of the Euler parameters $\dot{\underline{p}}$ is related to the local angular velocity $\underline{\omega}'$ (measured from angular rate sensors, Figure 3) by:

$$\dot{\underline{p}} = (1/2)\underline{L}^T\underline{\omega}' \quad (3)$$

where,

$$\underline{L} = \left[-\underline{e}, -\tilde{\underline{e}} + e_0\underline{I}\right] \quad (4)$$

The rate of change of the Euler parameters in Eq. (3) is a set of ordinary differential equations, which is integrated with a Runge-Kutta forth-order numerical method. The resulting Euler parameters are then normalised at each time step, from which the transformation matrix $\underline{A}$ can then be evaluated as,

$$\underline{A} = (2e_0^2 - 1)\underline{I} + 2\underline{e}\,\underline{e}^T + 2e_0\tilde{\underline{e}} \quad (6)$$

Accounting for the gravitational influence on the acceleration in the local frame $\ddot{\underline{r}}'$ (measured from accelerometers, Figure 2) at the initial orientation [1], the global acceleration $\ddot{\underline{r}}$ can then be calculated as:

$$\ddot{\underline{r}} = \underline{A}(\ddot{\underline{r}}' + \underline{A}_0^T\underline{g}) - \underline{g} \quad (7)$$

where $\underline{g}$ accounts for the gravitational influence.

A sample of the results on the ATD head kinematics from an HCT test is shown in Figure 4, and validity of the kinematics algorithm versus the photometric data is demonstrated. Overall this study indicates that the use of angular rate sensor and accelerometer data is an efficient and viable method in obtaining the kinematics of HCT in experimental testing.

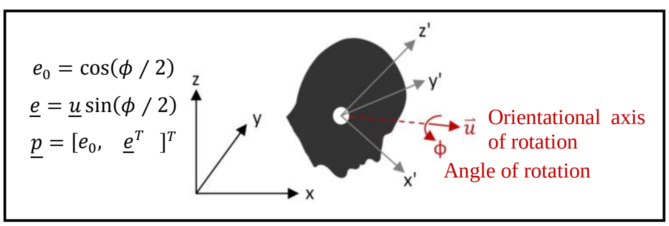

Fig. 3: Orientation of an object (such as an ATD head) using Euler parameters

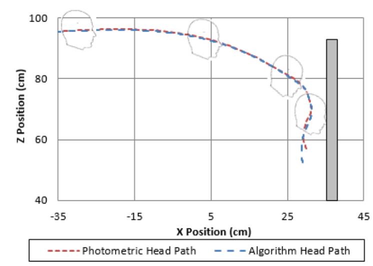

Fig. 4: Head displacement plot (with contact)

References

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