The tracking method of vehicle point or dummy point in the vehicle crash by calculating linear accelerometer and angular velocity

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ABSTRACT

From the mathematical equations we can get the point coordinates with 3 axis linear accelerometer and 3 axis angular velocity by integration. In this research, we will introduce two unique algorithms-acceleration method and velocity method of Hyundai-Kia motors and ACTs and prove the accuracy from many kinds of dummy inboard or outboard tracking case and vehicle body point.

Key Word : Gyro, Tracking, Vehicle Crash, Dummy, accelerometer, angular velocity

1. Introduction

Target tracking is useful in the vehicle crash test analysis because we can check the contact of 2 objects and compare what is different on the moving among the several tests.

If we use video target tracking, it takes some more time than point tracking by calculating 3 axis linear accelerometer and 3 axis angular velocity because we should convert the high speed film file and analyze by video tracking program like TEMA. Also, the resolution of tracking data become lower because the resolution of high speed film is 1,000Hz and that of sensor data is 10,000 Hz. The most important thing is video target tracking time is restricted in case of the head tracking because the head is commonly covered by curtain airbag and passenger airbag by test modes or rotates so the target is untraceable.

But we cannot conclude the point tracking by calculating 3 axis linear accelerometer and 3 axis angular velocity is always more useful, because we cannot use it on the deforming area of crash vehicle. The vibration during the deformation makes a kind of noise so the calculation becomes inaccurate. Also there must be some tolerance in the calculation method. (IMU company says the maximum tolerance is about 12mm in case of frontal sled head tracking). [1)~3)]

So we should mix these two types of method for proper purpose. In this research we will introduce two unique algoritms-acceleration method and velocity method of Hyundai-Kia motors and ACTs. We need only common 3 axis linear accelerometer and 3 axis angular velocity data and diadem software, not expensive sensor or software, so we believe this can be widely and easily used in crash analysis.

2. Main Subject

2.1 Theories and related formula in physics.

2.1.1 The velocity relative to fixed system "S"

Considering two axis systems, "S" fixed to ground and "S'" moving relative to "S".

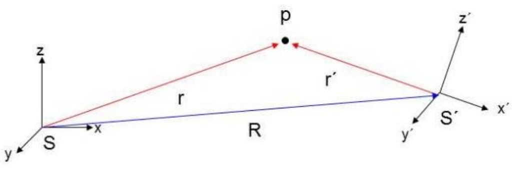
Considering a point in space, coordinates relative to the two systems are:

To "S": $\vec{r} = x\vec{i} + y\vec{j} + z\vec{k}$ (1)

To "S′": $\vec{r}' = x'\vec{i}' + y'\vec{j}' + z'\vec{k}'$ (2)

in velocity from position, the position must be differentiated through time.

$$\vec{v} = \frac{d\vec{r}}{dt} \quad (3)$$



To obtain the velocity relative to the fix systems "S",

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*** ACTS (Advanced Car Technology System) : Co-Author

the position has to be differentiated relative to the fix system "S".

$$(\vec{v})_s = \left(\frac{d\vec{r}'}{dt}\right)_s = \frac{dx'}{dt}\vec{i}' + \frac{dy'}{dt}\vec{j}' + \frac{dz'}{dt}\vec{k}' + x'\left(\frac{d\vec{i}'}{dt}\right)_s + y'\left(\frac{d\vec{j}'}{dt}\right)_s + z'\left(\frac{d\vec{k}'}{dt}\right)$$

(4)

The variation through time of the axis vectors represent the angular velocity of the axis. Therefore, the velocity of the point calculated relative to the fix system "S" is:

$$(\vec{v})_s = \left(\frac{d\vec{r}'}{dt}\right)_s + (\vec{w} \times \vec{r}') \qquad (5)$$

To obtain the velocity variation through time of the axis vectors represent the angular velocity of the axis. Therefore, the velocity of the point calculated relative to the fix system "S" is:

$$(\vec{v})_s = \left(\frac{d\vec{R}}{dt}\right)_s + \left(\frac{d\vec{r}'}{dt}\right)_s + (\vec{w} \times \vec{r}') \qquad (6)$$

But if S' is rotating in pitching sled, oblique or offset crash we should consider its velocity factor also.

$$(\vec{v})_s = \left(\frac{d\vec{R}}{dt}\right)_s + (\vec{w}' \times \vec{R}') + \left(\frac{d\vec{r}'}{dt}\right)_s + (\vec{w} \times \vec{r}') \qquad (6)'$$

2.1.2 The acceleration relative to fixed system "S"

To get acceleration, relative to the fix systems "S" the velocity has to be differentiated.

$$\vec{a} = \left(\frac{d\vec{v}}{dt}\right)_s = \left(\frac{d\vec{v}'}{dt}\right)_s + \left(\frac{d\vec{V}}{dt}\right)_s + \left(\frac{d(\vec{w} \times \vec{r}')}{dt}\right) \qquad (7)$$

The third term differentiates as follows:

$$\left(\frac{d(\vec{w} \times \vec{r}')}{dt}\right) = \left(\frac{d\vec{w}}{dt}\right)_s \times \vec{r}' + \vec{w} \times \left(\frac{d\vec{r}'}{dt}\right)_s = \left(\frac{d\vec{w}}{dt}\right)_s \times \vec{r}' + \vec{w} \times \left[\left(\frac{d\vec{r}'}{dt}\right)_s + \vec{w} \times \vec{r}'\right] =$$

$$= \left(\frac{d\vec{w}}{dt}\right)_s \times \vec{r}' + \vec{w} \times \left(\frac{d\vec{r}'}{dt}\right)_s + \vec{w} \times (\vec{w} \times \vec{r}') \qquad (8)$$

Remembering that from equation (5):

$$\left(\frac{d\vec{r}'}{dt}\right)_s = \left(\frac{d\vec{r}'}{dt}\right)_s + (\vec{w} \times \vec{r}')$$

Final acceleration relative to fixed system "S" is:

$$\vec{a} = \left(\frac{d\vec{V}}{dt}\right)_s + \left(\frac{d\vec{v}'}{dt}\right)_s + \left(\frac{d\vec{w}}{dt}\right)_s \times r' + \vec{w} \times (\vec{w} \times \vec{r}') + 2\vec{w} \times v' \qquad (9)$$

Which is same as

$$\ddot{\vec{x}}_{31} = \ddot{\vec{x}}_{32} + \ddot{\vec{x}}_{21} + \dot{\vec{w}}_2 \times \vec{x}_{32} + \vec{w}_2 \times (\vec{w}_2 \times \vec{x}_{32}) + 2 \cdot \vec{w}_2 \times \dot{\vec{x}}_{32} \qquad (10)$$

4)~5)

2.1.3 Two methods - from velocity or acceleration

To obtain position from the velocity calculation, one integration must be done from equation (6). In case of a sled test, the calculated point acceleration has to be integrated two times (ax,ay,az) to obtain point position (x,y,z). Also sled acceleration has to be integrated one time to obtain sled velocity which is considered the moving system's velocity and angular velocity is given.

To obtain position from acceleration calculation, two integration must be done. in case of a crash test, the calculated point has to be integrated two times (ax,ay,az) to obtain point position (x,y,z). Sled acceleration does not need to be integrated. Angular velocity is given. Then, acceleration can be calculated from equation (8).

For velocity method calculation in a crash test, only one point acceleration needs to be integrated. In order to obtain position, one integration of the complete velocity needs to be done. Consequently 3 integrations are needed.

For acceleration method calculation in a crash test, only one point acceleration needs to be integrated. In order to obtain position, two integration of the complete velocity needs to be done. Consequently 4 integrations are needed.

Comparing these two method in a crash test, we can expect velocity method would be more accurate because its integration number are smaller one time.

For velocity method calculation in a sled test, point acceleration and sled acceleration needs to be integrated. In order to obtain position, one integration of the complete velocity needs to be done. Consequently 4 integrations are needed.

For acceleration method calculation in a sled test, only one point acceleration needs to be integrated. In order to obtain position, two integration of the complete velocity needs to be done. Consequently 4 integrations are needed.

Comparing these two method in a sled test, we can expect acceleration method would be more accurate because there is no integration of sled axis which has bigger value than the others.

2.2 How to insert channels in diadem macro

We should be careful about the polarity and each axis definition when we use this macro. The inserting sequence can be list like Fig1.

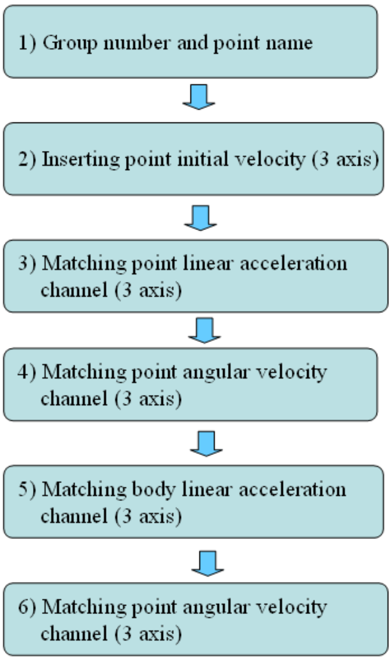

Fig.1 inserting sequence of the macro

Firstly, we should differentiate the group number and point name because when we do multi-calculation in one diadem file the previous calculation can be deleted unless we don't differentiate.

Secondly, we should insert point's 3 axis initial velocities because these are used to calculate the position. We should be careful for the macro unit, here we are using m/s, so NCAP x speed 56kph is 15.57 and Offset x speed 64kph is 17.78. The others be inserted as 0.

Thirdly, we should match the point's linear acceleration channels of 3 axis. We are using m/s2 and the polarity is same as SAE1733's which deceleration is plus in case of dummy contact to front airbag.

Fourthly, we should match the angular velocity channels of 3 axis. We are using rad/s and the polarity is same as SAE1733's.

Fifthly, we should match the body linear acceleration channels of 3 axis. We are using m/s2 and the polarity can be different by the case. In case of frontal sled test dummy head tracking the sled x axis pulse polarity is plus because when we compare and analyze it with video tracking the camera is onboard and it pushed the sled buck rear. In case of frontal crash test dummy head tracking the body x axis pulse polarity is minus because when we compare and analyze it with video tracking the camera is outboard and it pushed the car rear. If there is not y and z acceleration, we should match it with null channel which is automatically made by macro.

Sixthly, we should match the angular velocity channels of 3 axis. We are using rad/s and the polarity is same as SAE1733's. This terms are from equation (6)' and used only for body rotating case like pitching sled, oblique or offset crash.

2.3 Usage and confirming accuracy

2.2.1 Head tracking in YD NCAP sled and crash case

To confirm the accuracy, we chose YD US NCAP sled and crash case.

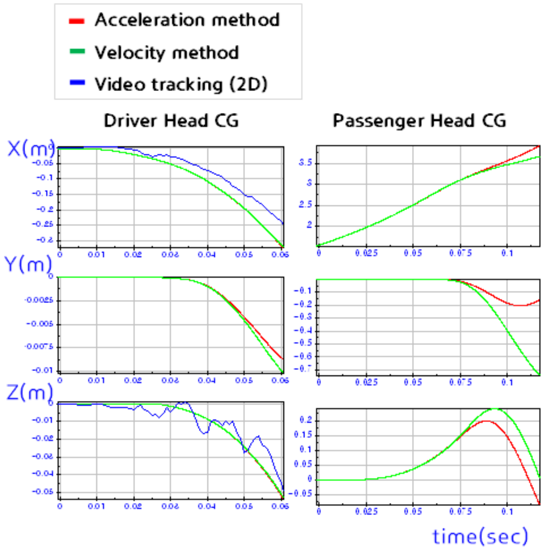

Fig.2 Head target tracking result in YD NCAP sled

When we review the sled target tracking, the acceleration method is very close to the velocity method till 100ms. But in case of passenger dummy the difference between them goes bigger (over 25cm), we can guess it comes from angular velocity tolerance which is 0.5°/sec in H3 50% percentile dummy but of 5°/sec in H3 5% percentile(10 times bigger tolerance).

The comparison with 2D video target tracking was not successful because there was big oscillation on the sled onboard camera. We compare it only for the driver.

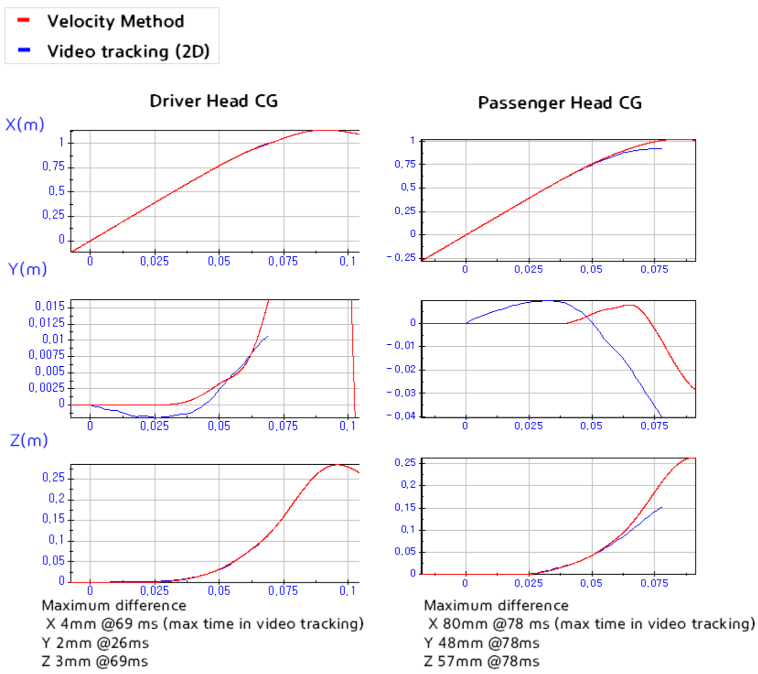

Fig.3 Head target tracking result in YD NCAP crash

In NCAP crash the comparison with 2D video target tracking was successful. The maximum tracking difference was 4mm below in driver. But in case of passenger it was much higher than driver, we guess this comes from also angular velocity tolerance which is 0.5˚/sec in H3 50% percentile dummy but of 5˚/sec in H3 5% percentile(10 times bigger tolerance).

Now the thinking in 2.1.3 that " we can expect acceleration method would be more accurate because there is no integration of sled axis which has bigger value than the others." in not so meaningful because the tolerance is too low in comparison with video tracking.

Comparison between sled and crash is not meaningful because sled test was done just as a base to confirm measuring method so we skip it here.

2.2.2 YD smalloverlap trolley ACU tracking case

In HKMC research with ACTs, we make YD smalloverlap trolley test for chassis and structure evaluation and its realization was quite close to the real crash. [6)]

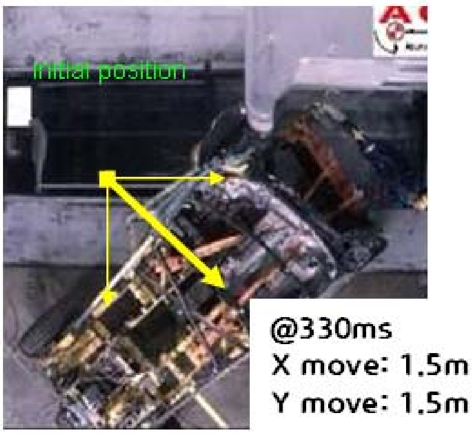

Fig.4 YD smalloverlap trolley video@330ms

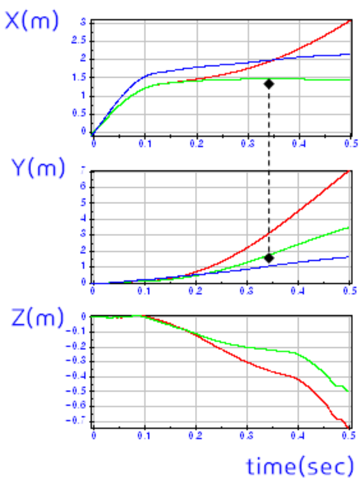

Fig.5 YD smalloverlap ACU positon tracking

In this test, we attached 3 axis linear accelerometer and 3 axis angular velocity sensorr to ACU (airbag control unit) position. Like NCAP sled head tracking result, acceleration method and velocity method tracking is close each other in 100ms but it becomes far. When we checked the video ACU position roughly which is possible to check to the time 330ms they matches to the tracking value x:1.5m and y:1.5m. We added similar place video tracking (cowl top tracking) in the graph, it is similar to the velocity tracking. So we can confirm the thinking in 2.1.3 that "we can expect velocity method would be more accurate because its integration number are smaller one time."

2.2.3 YD IIHS side trolley CG tracking case

In HKMC research with ACTs, we make YD IIHS side trolley test for the side structure evaluation and its realization was quite close to the real crash.

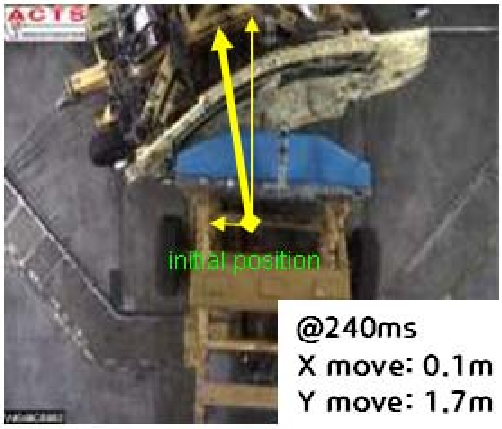

Fig.6 YD IIHS side trolley video@240m

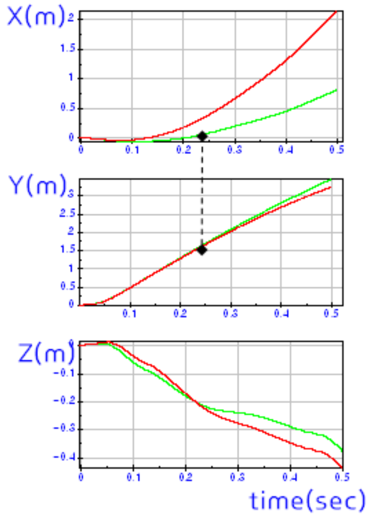

Fig.7 YD IIHS side trolley CG positon tracking

In this test, we attached 3 axis linear accelerometer and 3 axis angular velocity sensor to trolley CG. Like NCAP sled head tracking result, acceleration method and velocity method tracking is close each other in 100ms but it becomes far. When we checked the video CG position roughly which is possible to check to the time 240ms they matches to the tracking value x:0.1m and y:1.7m. There was no good video tracking position close to the trolley so we skipped to compare with video tracking. But we can confirm the thinking in 2.1.3 that "we can expect velocity method would be more accurate because its integration number are smaller one time."

2.2.4 YD US NCAP crash ACU tracking case

For more usage, in HKMC research with ACTs, we run the YD NCAP crash test with 3 axis linear accelerometer and 3 axis angular velocity sensor to ACU position

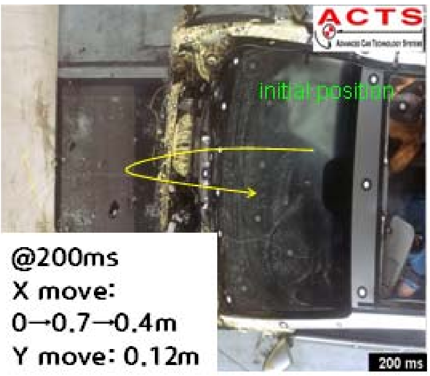

Fig.8 YD NCAP ACU video@200m

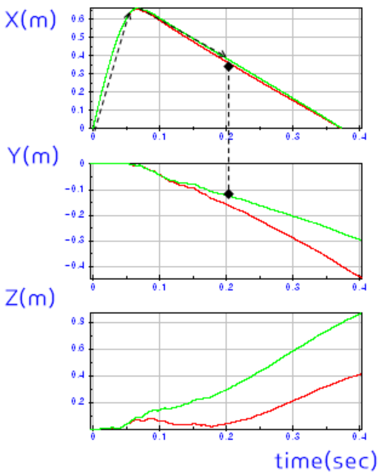

Fig.9 YD NCAP ACU positon tracking

In this test, like NCAP sled head tracking result, acceleration method and velocity method tracking is close each other in 100ms but it becomes far. When we checked the video ACU position roughly which is possible to check to the time 200ms they matches to the tracking value x: once maximum 0.7m and rebound to 0.4m and y:0.12m. There was no good video tracking position close to the trolley so we skipped to compare with video tracking. But we can confirm the thinking in 2.1.3 that "we can expect velocity method would be more accurate because its integration number are smaller one time."

3. Conclusion

As we discussed target tracking by calculating sensors is very useful in the vehicle crash test analysis because we can check the invisible area also. Now we developed HKMC and ACTS' unique calculating algorithm by the physical points moving vector equation. We did know below facts in this research.

1) The acceleration method is very close to the velocity method till 100ms.

2) The accuracy of velocity method was in 4mm in NCAP crash test H3 50% driver head tracking.

3) In case of passenger dummy the difference between them goes bigger (over 25cm), we can guess it comes from angular velocity tolerance which is 0.5°/sec in H3 50% percentile dummy but of 5°/sec in H3 5% percentile(10 times bigger tolerance).

4) For the body point tracking, only velocity method was accurate because its integration number are smaller one time than acceleration method.

■ Patent No. : Be submitted Diadme macro target tracking by 3 axis accelermeter and 3 axis angular velocity sensor

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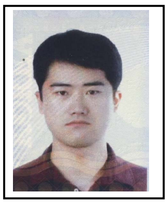
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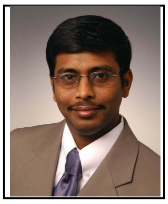
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