

**IVSS Project. INS (Inertial Navigation Systems in Crash Test Dummies). Phase 1.
Executive summary.**

Introduction, summary and general conclusions

The main objective with the IVSS Project Inertial Navigation Systems in Crash Test Dummies, phase one, was to investigate how Imego's INS could be used to study the loading of the chest, neck and head in crash test dummies. A final result from the project would be to outline the requirements from the automotive industry for a modified version of such an INS.

Initially the preliminary requirements from Autoliv, Saab and Volvo were compiled in order to investigate if the existing INS-version could be used in the various tests that were planned. These preliminary requirements from Autoliv, Saab and Volvo on the INS to be evaluated are seen in table 1 below. The corresponding specification for the evaluated INS is also shown in table 1. From table 1, it is seen that already the existing INS would serve this purpose and therefore no modifications were necessary before the tests.

	Req. Autoliv	Req. Saab	Req. Volvo	Spec. Imego	Comments
Range acc.	+/-50 g	+/-40-70 g	+/- 80-90 g	+/-50 g	Relevant tests could be done
Accuracy acc.		+/-1 %	+/-1 %	+/-0.2 %	
Range angular velocity	+/-3000 deg/s	+/-3000 deg/s	+/-2000 deg/s	+/-3600 deg/s	
Accuracy angular velocity		+/-1 %	+/-1 %	+/-0.2 %	
Range angular acceleration	+/- 170 000 deg/s ²			~ +/- 700 000 deg/s ²	Real data higher (1 100 000 deg/s ²)
Accuracy displacement	30 g/50 ms: Typically 1 mm				Verified by analysis
Bandwidth acc.	250 Hz	250 Hz		250 Hz ^{*)}	^{*)} Verified during evaluation
Bandwidth angular acc.	250 Hz	250 Hz		250 Hz ^{*)}	^{*)} Verified during evaluation

Table 1. Requirements and specification on the INS which was evaluated

There is also a requirement on wireless communication in the final product from the car industry. Such a feature does already exist but it could not be implemented in the INS used for this evaluation due to limitations in space in the head of the crash test dummy.

The final INS product must also be decreased in size, down to typically 30x30x30 mm, compared to the current version of 5x25x165 mm.

The INS was equipped with a protective cover, “a chimney”, and then integrated into a Hybrid III dummy head. This dummy head was then used for all tests at Autoliv, Saab and Volvo.

Several studies were performed in neck pendulum tests, torso launcher tests, FMH-tests (Free Motion Head form) and also investigations related to head rotational measurements. Some theoretical studies were also done to compare the accuracy, and the impact from various error sources, between the INS and conventional systems that are used today. In addition, the displacement error after a typical linear motion was calculated. Furthermore, a simple animation model was developed. The results from the tests and one theoretical study are summarised in the respective appendixes. These short versions of the reports are included here in order to give some feeling of the different types of tests that were done, but they must never be used as underlying documents for technical and scientific discussions etcetera. (The references to the complete test reports and theoretical studies are given in appendix 7.)

The INS principle of operation and its possibilities were explained also to personnel not directly involved in the program. In this way test engineers and researchers at Autoliv, Saab and Volvo got an insight in the new technique.

The tests were in general very successful and the results from them more than sufficient to establish a solid base for future work. We did of course also experience some problems during the project. One such experience was the importance of the origin of the INS related to that of the conventional reference sensor. Thus, the data from the INS and the reference sensor must be calculated relative one common origin (zero) with very high precision, in the order of millimetres.

The evaluated INS worked in accordance with its specification, see table 1 above. However, Autoliv, Saab and Volvo have some additional requirements on the final INS product. Therefore, three minor changes to the final measurement specification should be done; the accelerometer measurement range should be increased from 50 g to 200 g, the accelerometer bandwidth to 2 kHz and the bandwidth of the gyro should be validated for higher frequencies than 250 Hz. These modifications are trivial and the challenge in a possible next project phase is the miniaturisation of the INS down to typically 30x30x30 mm. (The requested wireless communication from the automotive industry is already available but was not used in this project phase.)

It is reasonable to believe that a miniaturised version of the INS would give some new and very important possibilities in terms of the studies of various loading effects of the chest, neck, feet and head in crash test dummies:

- Brain injury sensor
- Chest deflection sensor
- Wire less communication for FMH-investigations
- Complement and /or replacement of film analysis, when the view of the dummy is hidden by an inflated airbag.
- Measurements in a small space, (a foot)
- Differential measurements between crash test dummy and car

Project organisation etcetera

The core team in the project was:

Autoliv: Stig Berg and Håkan Pettersson

Imego: Dag Billger and Duncan McLeod

Saab: Christer Johnsson

Volvo: Roland Andersson and Sandra Laine-Hedblom

Project leader: Håkan Pettersson, Autoliv

Steering committee:

Autoliv: Ola Boström

Imego: Peter Björkholm

Saab: Magnus Holmquist

Volvo: Lotta Jakobsson

We had six project meetings and two meetings in the steering committee during the project from September 2004 to April 2005.

Project economy. Preliminary.

	Industri		Imego		Budget tot
		Utfall kSEK		Utfall kSEK	kSEK
Löner Autoliv		220			154
Löner Saab		116			92
Löner Volvo		177			92
Löner Imego				586	584
Löner totalt					922
Maskk. Autoliv		40			100
Maskk. Saab		62			98
Maskk. Volvo		124			98
Maskk. Industri					296
Material Imego				4	10
Övrigt				11	5
Summa		739		601	1 228

Appendix

1. Summary of dummy neck calibration test at Autoliv
2. Summary of head rotational test at Autoliv
3. Summary of FMH-test at Saab
4. Summary of Torso Launcher test at Saab
5. Summary of dummy neck calibration test at Volvo
6. Technical note. Calculation of the Accuracy of the position of the IMU after a linear displacement
7. References. Important reports from the project

Håkan Pettersson and Stig Berg , Autoliv
2005-04-07

IVSS. Inertial Navigation System in Crash Test Dummies. Comparison between the results from IMEGO's IMU and reference sensors during a standard dummy neck calibration test.

The aim of this test was to compare various results from Imego's IMU (Inertial Measurement Unit) with those obtained from reference sensors during a standard dummy neck calibration test. In this test, the rigid rod with neck and head attached is lifted to approximately two meters and thereafter released resulting in a pendulum movement which is stopped at a standard honey comb structure attached to a fixed steel structure. A part of the test set up is seen in figure 1.

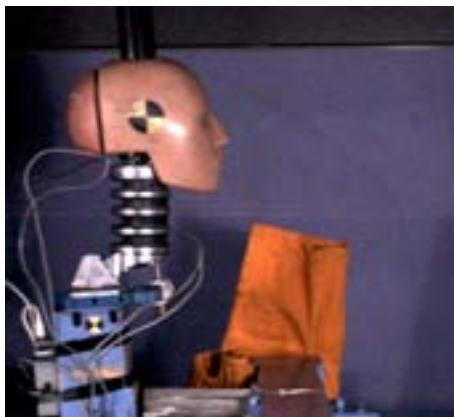


Figure 1. Part of test set up for neck calibration pendulum test

The IMU was mounted in the head of the dummy in the position where the reference sensors normally are located, while the reference accelerometer itself in this case was mounted 5.5 cm below and 2 cm behind the IMU. In addition, two potentiometers, one located in the head and the other in the rigid pendulum, were used to calculate the angle versus time during the test.

There were some obvious differences between the INS signals and those from the reference sensor(s). This difference when observed first can be explained by the fact that the reference accelerometer and the IMU had slightly different locations. (See Imego's report: 110056_autoliv_field_1_rep_rev_2.doc)

Reference to the complete report:

S. Berg and H. Pettersson. "Comparison between the results from Imego's IMU and reference sensors during a standard dummy neck calibration test". Autoliv Test report 2005-02-21.

Håkan Pettersson, ALR
2005-04-07

IVSS. Inertial Navigation System in Crash Test Dummies. Rotational Measurements of the Head during a Simulated Side Impact.

The head of a Hybrid III dummy, equipped with Imego's IMU (Inertial Measurement Unit), was mounted in a two-wire pendulum. The head was raised and then released resulting in a pendulum movement with the head impacting on an Inflatable Curtain, mounted on a test fixture, see figure 1. The impact speed was about 7 m/s in all tests. In addition, the dummy head could be rotated along its vertical axis making it possible to study the influence from different impacting angles. (The dummy head could of course rotate freely after the impact.) Typical angular rate and angular rate acceleration during an impact on a non-inflated curtain is seen in figure 2.



Figure 1. Test set-up

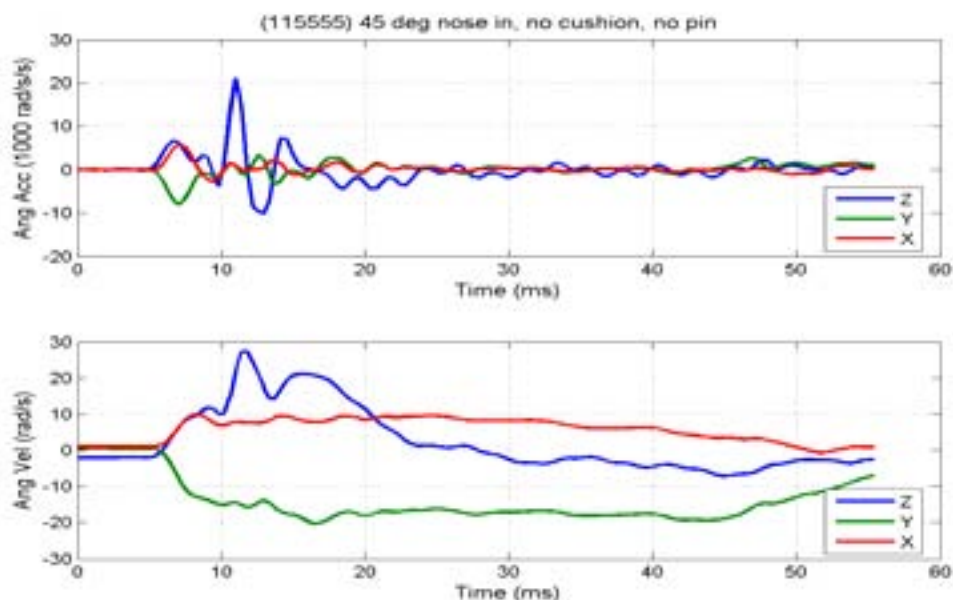


Fig 2. Typical angular rate and angular rate acceleration during an impact on a non-inflated curtain

Several tests with different impacting angles, with and without the Inflatable Curtain, were performed.

The results show that the Inflatable Curtain has a dramatic effect on both angular velocity and angular acceleration. The maximum angular acceleration is reduced from about 20 krad/s² to 1 krad/s² due to the Inflatable Curtain.

The maximum measured angular acceleration is very close to the estimated maximum bandwidth for the solid gyroscope, which should be addressed in future studies.

Reference to the complete report:

H. Pettersson. "IVSS. Inertial Navigation System in Crash Test Dummies. Rotational Measurements of the Head during a Simulated Side Impact". Autoliv Technical Note, 2005-02-21.

Christer Johnsson, Saab
2005-04-07

IMU in FMH-test



Test description

The test was performed as a general FMH-test (Free Motion Headform) against b-pillar. The measured data from the IMU provides a very good representation of the flight. Most important in FMH-tests are acceleration, velocity and orientation.

Date of test: 2004-12-21

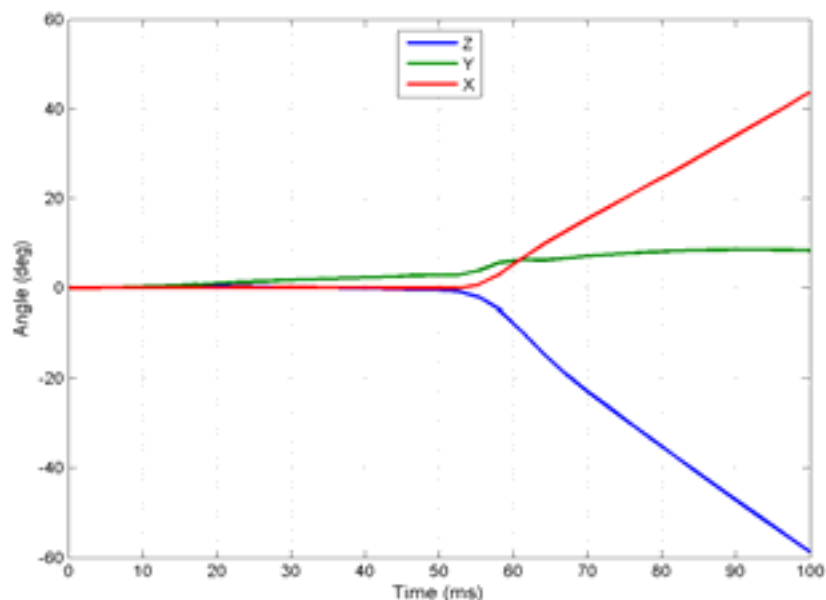
Test location: Saab FMH-laboratory

Conclusions

The measured data from the IMU provides a very good representation of the flight. This information should also be useful in simulation works.

If size, weight, measurement ranges and sampling rates will be changed, the IMU system will be very useful in FMH-tests. In FMH-tests today, the sensor cables influence the test. Therefore a wireless IMU system is the optimum.

Orientation



Reference to complete report:

C. Johnsson, "IVSS Inertial Navigation System in FMH-test"

Saab Test Report 2005-01-17 TCG-05-001

Christer Johnsson, Saab
2005-04-07

IMU in sled test



Test description

The tests were performed in Torso Launcher test rig with a dummy in a car seat which was mounted on the sled. Two trials at approx. 12 km/hr and two trials at approx. 18 km/hr were performed

The most interesting parameters except acceleration are angular rate and angular acceleration.

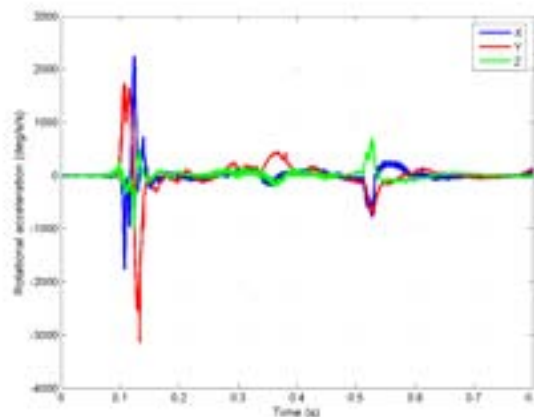
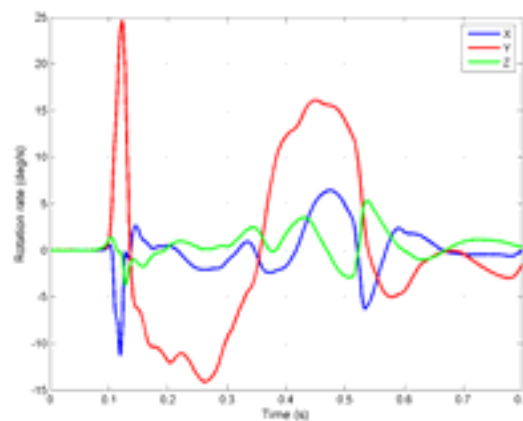
Date of test: 2005-03-29

Test location: Saab test-laboratory

Conclusions

The measured data from the IMU provides a good representation of head movements during sled tests. Probably it will work excellent in vehicle crash tests as well.

Angular rate and acceleration at 17,7 km/hr



Reference to complete report:

C. Johnsson, "IVSS Inertial Navigation System in sled-test"

Saab Test Report 2005-03-31 TCG-05-005

Roland Andersson, VCC
2005-04-07

IMU in Dummy neck calibration stand



Test Description

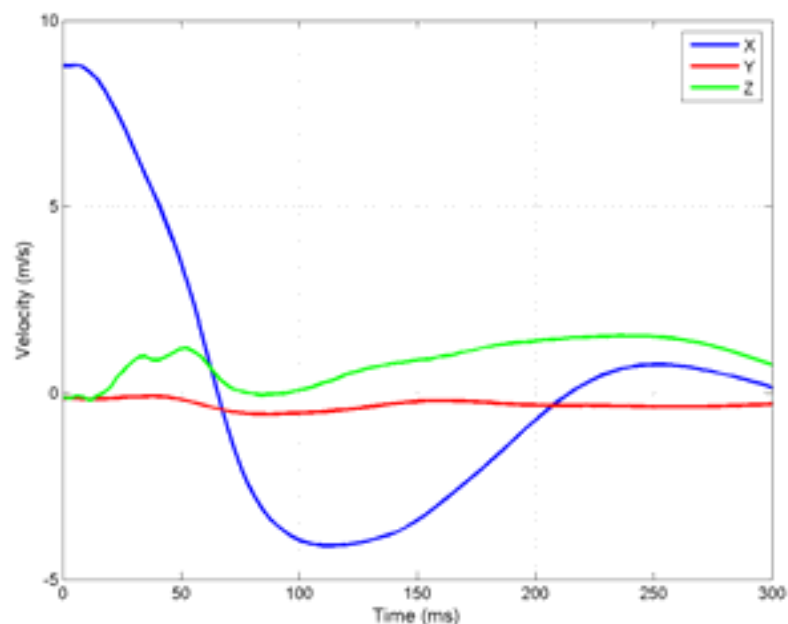
The test was performed in order to compare the signal from the IMU with reference signals from transducers in dummy head and neck calibration test stand.

Parameters to compare: Acceleration, velocities and velocity speeds.

Date of test: 2005-02-22

Test Location: Volvo Cars Safety Centre

Example of result



Reference to complete report:

R. Andersson. "Summary of results between IMU and reference sensors in Dummy neck calibration stand.", Test summary, 2005-04-05.

Håkan Pettersson, ALR
2005-03-08

Technical Note

IVSS. Inertial Navigation System in Crash Test Dummies. Calculation of the Accuracy of the Position of the IMU after a Linear Displacement.

Introduction

Imego's IMU (Inertial Measurement Unit) has been tested and evaluated in several relevant test situations at Saab, Volvo and Autoliv within the IVSS-project. But there is one interesting situation related to the deflection of the chest during deceleration, which has not yet been experimentally studied in this project. However, it is possible to perform a simple calculation of the accuracy of the data from the IMU sensors in this, which might replace an experimental test in the first phase of the project.

One interesting case is to study the chest deflection during 50 ms when decelerated linearly with 30g. This gives a total displacement, or movement, of about 37 cm, and the required accuracy in end position should not exceed 5 mm. The rest of this short technical note will discuss the error contribution from various sources.

Discussion

Seven different error sources will be discussed separately below.

1.1.1 Error from the noise

The noise of the accelerometer is $100 \mu\text{g}/\text{SQRT}(\text{Hz})$, which is about 1.6 mg if we assume a bandwidth of 250 Hz. If we make an extremely conservative approach, assuming that the noise is constant over 50 ms, and double integrate, we get an error of 0.02 mm.

1.1.2 Error from misalignment

The misalignment of the sensors within the IMU is less than 0.02 deg. This will of course change the scale factor. The total error is 0.13 mm.

1.1.3 Non-accuracy error

The non-accuracy of the accelerometer is 2000 ppm of measured value. Again if we assume a worst case scenario and double integrate over 50 ms we get an error of 0.7 mm.

1.1.4 Non-linearity error

The non-linearity error is 400 ppm, which is small compared to the non-accuracy error. This contribution can therefore be neglected.

1.1.5 Error due to the g^2 -sensitivity

The nominal g^2 -sensitivity of the accelerometer is $5 \text{ mg}/g^2$. At a constant acceleration of 30 g over 50 ms this yields an error of approximately 0.2 mm .

1.1.6 Error due to bias stability

The bias stability is $100 \mu\text{g}$. A worst case scenario gives an error of 0.001 mm after double integration over 50 ms .

1.1.7 Error introduced by the A/D converter

The measurement range of the accelerometer is $\pm 50 \text{ g}$. If we assume a 10 bit A/D-converter, we get a least significant bit corresponding of 0.1 g . But if we assume a sampling rate of 20 kHz we get 1000 samples over 50 ms , The noise associated with the quantisation is reduced proportionally to $1/\text{SQRT}(1000)$ resulting in an average quantisation error of 3 mg . If we now double integrate over 50 ms we get 0.04 mm .

1.1.8 Total error

Most of the error sources above should be considered to be independent of each other. Therefore, the individual error contributions should be added quadratically resulting in a total error of 0.74 mm .

Conclusion

The total displacement error has been estimated to be less than 1 mm in this case. This should be compared to the requirement of 5 mm . In addition, extremely conservative assumptions have been used in most of the calculations above. The performance should be better than this. By comparison, in another Imego project, the GSE project (GPS Shadow Explorer), accelerations of about 1 g over 5 seconds were typical and the non-accuracy error of 2000 ppm would here be estimated to be about 25 cm , whereas in the final results the total error was of the order of 6 cm .

References

General documents

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Technical reports

4. D. Billger and D. McLeod. "Enhancing Vehicle Safety Testing with Inertial Navigation", Imego magazine 2005.
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