Event Detection - Automatic Detection of Anomalies for Time History Curves in Crash

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Abstract

With the rapid development of AI applications in the recent years the ever growing amount of simulation runs being performed has even more increased, especially with respect to provide simulations to train the AI models with. While current Simulation Data Management systems and the IT infrastructure already allow storing and accessing huge datasets and would facilitate putting this into action for analysis, the users usually only have tools and the time to make rather straight forward model to model comparisons, between current model versions and their immediate predecessors. Making use of the Principal Component Analysis, a dimension reduction algorithm out of the unsupervised learning techniques, a new database was developed and presented in the last NAFEMS World Conference. Continuously being fed with new simulation runs, this database enables us to automatically detect unknown behaviour in the most recent simulation runs compared to all predecessors at a time. To achieve this, the database does not only need to store and detect every new deformation pattern, but in addition several obstacles like a mapping between different simulation models, a performance efficient database format and a technique to also detect local effects had to be addressed. Taking a look at the special needs from engineers to also being able to include history curves into the analysis, the database now had to be extended to also being able to not only store and compress the curve data, but also use the outlier detection on the history data. Furthermore in case a deeper analysis of the curve anomaly is being needed it is shown how structural part deformation behaviour can be correlated against the curve information to derive not only curve to curve relationships, but also being able to compute part to curve correlations. Thus engineers become able to derive design suggestions which lead to an improvement in curve behaviour. In addition the search for deformation patterns had to be extended to also being able to search for similarities among time history data, to being able to identify simulations with a similar behaviour.

1. Database

In order to make use of all simulation results during model development a compressed database has to be deployed which grants access to every result also at a later stage of development.

We investigate a set of 50 LS-DYNA simulations of a sensitivity analysis for the model “Chrysler Silverado” [1], with 152 time steps each. The original size is 452.7 GB. Applying an industry standard compression on each simulation result individually [2], we can reduce the data size to 7.1 GB.

Incorporating also dependencies between simulation results, so that only differences are being stored [3], we achieve a compressed size of 1.4 GB. Thus exploiting the similarities between simulation results improves the compression efficiency by a factor of 5.1.

Making use of the similarities between the simulation results during the development phase therefore allows for a higher compression, which was the initial enabler for the development of algorithms to detect unknown behaviour.

While in the first phase the database supported the simulations geometry as well as post-values, in a second phase the database got extended to also being able to store time history curve.

2. Time History Curves

Time history curves not only help to break down the crash into phases (e.g., pre-impact, impact, post-impact), enabling better comprehension of different forces and deformations at each stage but also help evaluating of structural integrity. By examining force and acceleration curves, engineers can e.g. assess how much force is experienced by critical parts of the vehicle, helping to identify potential structural failures, as time-history curves highlight the maximum forces or accelerations experienced during the crash, which are crucial for evaluating whether safety standards are met.

Especially with respect to injury prediction and occupant safety as well as airbag deployment time history curves play an important role. The Head Injury Criterion (HIC), for example, is a measure often derived from acceleration-time curves during a crash. In physical tests, the actual crash results are measured using a dummy (like a Hybrid III dummy or THOR dummy). In simulations, similar time-history curves are generated for the occupant model. By comparing these curves, engineers can assess whether the predicted injury criteria (e.g., HIC, chest deflection, neck forces) from the simulation align with the real-world injury outcomes from the physical crash tests.

Additionally when it comes to comparing test and simulation a test-scan of an occupant after the crash is not of much help as the dummy’s position after the crash is not reliable which is why especially curves are taken into account to analyse the occupants dynamics during the crash.

Also with respect to upcoming importance of curve analysis for Euro NCAP implementation 2024, where within the report, the exact same simulation shall be repeated twice and resulting curves put into an overlay for comparison, shows the importance of curve analysis [4].

3. Event Detection

In a vehicle product development cycle, numerical simulations have vastly enhanced efficiency and pace of evaluating evolving designs over the course of development. One of the several challenges that remain in such a process is to be able to accurately and easily spot unwanted behaviours as a consequence of design changes, which other-wise is a laborious and time-intensive process and moreover many a times, important behaviours accidentally go unnoticed.

The aforementioned issue is addressed by automatically flagging newly found behaviours termed as Events for every new simulation that is imported into the database. This is achieved through characterizing and learning deformation patters by employing principal component analysis, a popular unsupervised machine learning technique. Thus it is possible to extract and store rich insights into the database from simulation runs at a fraction of disk space, in comparison with original runs. In addition, the database also grants access to the Engineer to seamlessly search for similar deformation patterns across all the runs in the database in an interactive manner.

4. Event Score & Part Fragmentation

The detection of new events, as mentioned earlier, relies on an outlier score calculation based on PCA. This results in an event score for each part and time-step within the range of [0:2], indicating the degree of unfamiliar behavior the event represents. The event score provides immediate feedback to the engineer regarding the strength of the outlier, with the score value indicating its intensity. A score below 1 suggests familiar behavior, while scores above 1 indicate unfamiliar behavior. The higher the score, the more pronounced the outlier.

In the context of analyzing crash structures, it is essential not only to highlight entire parts that are conspicuous but also to pinpoint the specific local segment of the part exhibiting the unusual behavior. To support this, parts are internally divided into fragments, ensuring high geometric resolution for detecting localized events. In addition to geometry, post-processing values such as strains, stresses, and failures are also analyzed.

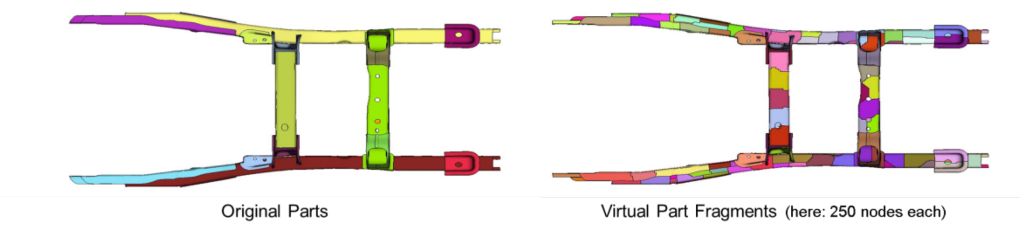

Figure 1: Decomposition of parts to detect local events. Geometry taken from the example case: Chevrolet Silverado [1]

5. Test Scenario

The test scenario shown here is based up on a DOE from the Chevrolet Silverado [1] for which the thickness of parts is being varied. Exemplary curves were generated based up on the displacements of selected nodes.

Incrementally adding the simulations to the analysis database, the simulations throw both, geometrical as well as curve related Events. As of at the time of writing this abstract curve handling was implemented for PCA analysis and correlation analysis but not yet complete for the automatic detection of unknown behaviour, an exemplary event curve was chosen, see Fig. 2. The curve set shows a strong variation among the simulation runs and was a good candidate to show the principle workflow. The before mentioned addition to the database to being able to analyse curves is about to be finished to extend the functionality towards the automated curve analysis. Spotting and raising outliers, while known behaviour is not generating any event.

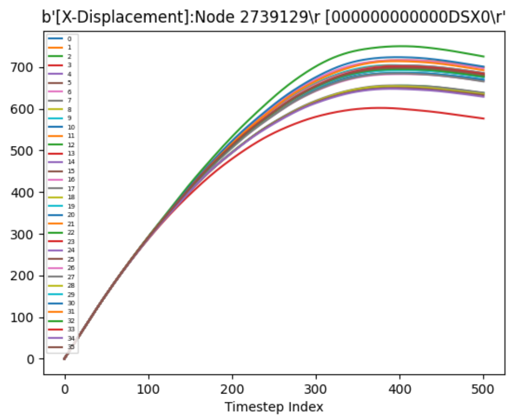

Figure 2: Scatter of example curve from NODE 2739129, showing spread of behaviour over simulations

Having such outliers for curves also puts us into the position to identify possible root causes for both curves and geometrical events which can both be achieved with applying the PCA to derive causal chains (see [6] for additional insights) as is shown conceptually in the next part.

Assuming the curve got raised automatically as an outlier, the example curve dataset of NODE 2739129 has been forwarded to the DPCA toolchain, for which the curve integration is already done, allowing analyzing its correlation towards parts. Exemplary shown is such a correlation towards the variation of the firewall (Fig. 3), which happens to show a strong correlation in its behavior with the curve, see Fig. 4.

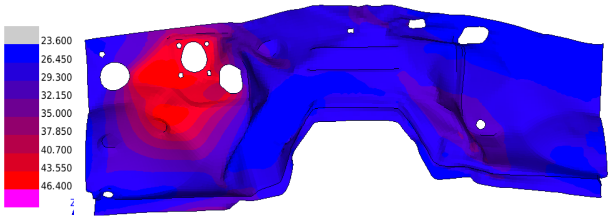

Figure 3: Maximum variation among all the simulations in [mm], highlighting regions of strong deviation among all simulation runs for the firewall

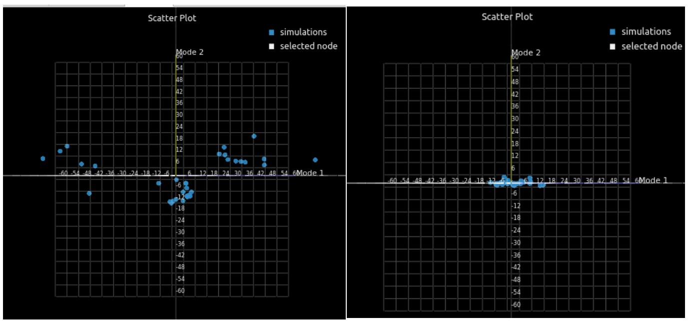

Figure 4: Scatterplot of the Firewall PCA(left) and DPCA(right), highlighting the reduction of scatter after subtraction(right) of the dominating curve mode

In the next steps of the analysis it is planned to automatically determine the correlation of all parts towards the curve, such that an automated process as known from part only analysis can be deployed. This will finalize the automatic detection of events towards and additional automatic detection of the root cause.

6. Summary

In this conference paper it is illustrated how a database used for automatic event detection was extended to also incorporate time history curves. These curves help to break down crash events into phases (pre-impact, impact, post-impact), and enable better understanding of forces and deformations at each stage.

By adding curve analysis to the database, the tool chain can automatically detect outliers in curves, while known behavior generates no events, thus improving the detection of unusual behaviors within simulation runs with the extension of not only focusing on geometry and post-values but also having the chance to sport curve anomalies.

In the end it is also shown with a small example how this allows determining correlations of part scatter towards curve scatter.

7. References

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