

Estimating Head Trauma Metrics in Pedestrian Collisions Using Frequency-Domain–Based Deep Neural Architectures

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Abstract

Due to the growing number of vehicle–pedestrian collisions around the world, pedestrian safety has become a major concern in modern car design. The Head Injury Criterion (HIC) is a widely accepted measure for determining how bad head injuries are when people are hit by cars. In the past, physical headform impact tests done according to standard testing procedures were used to get HIC values. These experimental methods are dependable, but they take a lot of time, cost a lot of money, and aren't very flexible when it comes to testing different vehicle design options. So, there is a growing need for effective predictive methods that can accurately guess HIC values in the early stages of design without the need for a lot of physical testing.

This research introduces a Frequency Response Function (FRF)-based Deep Neural Network (DNN) model for forecasting HIC through dynamic stiffness measurements. The study commences by examining the intrinsic relationship between dynamic stiffness properties and HIC values through a simplified steel plate framework. The analysis of the steel plate was done to see if frequency response and stiffness-related features could be used as predictive parameters. The initial results validated a quantifiable correlation between dynamic stiffness behaviour and HIC, suggesting that frequency-domain attributes may function as significant inputs for machine learning-driven injury prediction.

After the initial validation, the suggested method was used to look at the hoods of two real cars. Real vehicle hoods are not like the simple steel plate. They have complicated shapes, support structures, and parts underneath them, like engines, brackets, and support frames. Experimental assessment indicated substantial disparities between the steel plate correlation and actual hood outcomes. The main reason for these differences was how the hood panel and the lower structural parts interacted during the impact. The hood's penetration into these underlying parts changes the effective stiffness that the impacting headform feels, which in turn changes the HIC values.

To deal with these complicated physical problems, a Deep Neural Network model with many features was made. The model used dynamic stiffness parameters from Frequency Response Function analysis and other structural features to show how impact behaviour and injury outcomes are related in a nonlinear way. Also, a penetration estimation algorithm was made to figure out how much the hood bent into lower parts during impact events. We added this penetration depth feature to the neural network as an extra input parameter. This made the predictions much more accurate and cut down on the number of mistakes.

The improved DNN model was much better at learning about complicated structural interactions and predicting HIC values than traditional correlation-based methods. The proposed framework combines frequency-domain mechanical analysis with cutting-edge AI methods to create a hybrid approach that fills the gap between experimental testing and data-driven modelling.

The findings of this study underscore the efficacy of FRF-based Deep Neural Networks as valuable supplementary instruments in vehicle design and pedestrian safety evaluation. The model makes it possible to quickly test changes to the hood, materials, and structure without having to do headform impact tests over and over again. An AI-assisted predictive system like this can help automotive engineers make better hood structures to protect pedestrians better in the early stages

of design. This will lead to safer vehicle development and lower testing costs.

In summary, this study shows that combining dynamic stiffness analysis, penetration estimation algorithms, and deep learning methods is a promising way to accurately and intelligently predict the Head Injury Criterion in pedestrian crash situations.

Keywords: Head Injury Criterion (HIC), Deep Neural Networks, Frequency Response Function, Pedestrian Safety, Dynamic Stiffness Analysis.

I.INTRODUCTION

Road traffic accidents are still one of the most common causes of death and injury around the world. Pedestrians are especially at risk among road users. As more people move to cities and more cars are on the road, making sure that pedestrians are safe has become a very important goal in modern automotive engineering. Regulatory bodies worldwide have implemented rigorous safety standards designed to reduce pedestrian injuries in vehicle-pedestrian collisions. The Head Injury Criterion (HIC) is one of the most well-known biomechanical injury assessment metrics for determining how serious a head injury is. HIC looks at the history of acceleration and time during an impact to figure out how likely it is that someone will get a head injury. It is often used in pedestrian headform impact tests to see how safe a vehicle's hood is.

In the past, controlled headform impact tests done in standard testing conditions were the only way to get HIC values. These tests need advanced tools, fast data collection systems, equipment to measure dynamic stiffness, and very accurate setups for impacts. Even though these kinds of physical tests give accurate and reliable results, they cost a lot of money, take a lot of time, and use a lot of resources. Engineers often have to look at many different design changes during the iterative stages of vehicle hood design. These changes can include changes in the properties of the materials, the distribution of thickness, the placement of reinforcements, and the clearances under the hood. It is not practical to do full-scale experimental tests on every design change, and it costs a lot more money and takes a lot longer to get to market.

Recent progress in computational modelling, machine learning, and deep learning has made it possible to predict complicated physical phenomena without having to do experiments all the time. Artificial Intelligence (AI) methods, especially Deep Neural Networks (DNNs), can find nonlinear connections between input variables and target outputs in very complicated systems. AI-based predictive models might be able to learn how structural stiffness, impact dynamics, and injury criteria like HIC are all related when it comes to keeping pedestrians safe. Using computational intelligence, it is possible to rely less on repeated physical crash tests while still getting very accurate predictions.

The current research investigates the viability of forecasting HIC values through a Frequency Response Function (FRF)-based Deep Neural Network framework. To begin, a simplified steel plate model is used to look into the relationship between dynamic stiffness and HIC. This baseline study aims to ascertain the validity of stiffness-related characteristics in offering significant predictive insights into the severity of head injuries. The analysis of the steel plate shows a measurable and understandable link, which shows that it is possible to use stiffness-based parameters as inputs for machine learning models.

The methodology is then expanded to examine the hoods of two manufactured vehicles. Real vehicle hood systems are made up of many parts that work together, such as reinforcement ribs, inner panels, engine parts, brackets, and support structures. The simplified steel plate is not one of these parts. Experimental observations show that the predictions made with steel plates are very different from the actual results of the hood. Most of these differences are caused by the way the hood and the understructure interact during an impact. When a headform hits the hood, it can change the effective stiffness and have a big effect on HIC values by hitting lower parts of the hood.

To solve this problem, we created a Deep Neural Network model that uses more than one input feature. An algorithm is created to estimate how deep the hood penetrates into the underlying parts, in addition to dynamic

stiffness parameters that come from frequency response analysis. This penetration estimate is an important part of taking into account the effects of structural coupling and nonlinear deformation behaviour. Adding this extra parameter greatly improves the DNN model's ability to make predictions.

The main goal of this study is to show that AI-assisted predictive modelling can be used as an extra tool for assessing vehicle safety and improving hood design. The proposed framework seeks to offer a quicker, more affordable, and precise substitute for traditional experimental methods by integrating mechanical analysis with deep learning techniques. In the end, this method helps make vehicle designs safer and makes the engineering process easier when it comes to analysing pedestrian protection.

II.LITERATURE REVIEW

Several researchers have looked into ways to predict head injuries in pedestrians when cars hit them. Conventional research predominantly utilised physical crash tests and numerical simulations to calculate the Head Injury Criterion (HIC), a commonly employed metric for evaluating the severity of head trauma during impacts.

Initial investigations examined the application of machine learning models to forecast HIC values from crash data. A study by Vikas Hasija and Erik Takhounts created a predictive model using crash-test datasets from the National Highway Traffic Safety Administration database as an example. The researchers used machine learning methods like logistic regression to sort HIC levels into low, medium, and high injury categories. This shows that data-driven methods can accurately guess how bad an injury is without having to do a lot of physical testing.

Subsequent research augmented the application of machine learning algorithms for pedestrian safety analysis. Researchers created models that use things like bonnet stiffness, impact location, and under-hood clearance to guess HIC values when a vehicle is first being designed. These methods showed that machine learning can predict how well a head injury will perform with reasonable accuracy and help make the front end of a vehicle safer.

Recent research has incorporated deep learning methodologies to enhance predictive accuracy. For example, research on pedestrian protection performance has employed deep neural networks to examine intricate correlations between vehicle structural parameters and head injury results. These models let engineers quickly check how safe it is for pedestrians and improve the structures of vehicles without having to do expensive tests all the time.

Other researchers have also looked into integrated vehicle safety systems that combine active safety technologies, like controlling the brakes, with passive protection systems, like hood airbags. These studies showed that advanced safety systems can lower HIC values and make pedestrians safer by simulating how vehicle parts interact with pedestrian impacts.

In general, earlier studies show how important data-driven prediction models, machine learning methods, and advanced safety design strategies are for making pedestrians safer. But a lot of the methods that are already out there either depend too much on simple models or don't take into account how the vehicle hood and underlying structures interact in a complex way during an impact. To get better and more accurate HIC predictions, we need more advanced predictive frameworks that use both mechanical analysis and deep learning.

III.METHODOLOGY

The suggested system uses a Frequency Response Function (FRF) based Deep Neural Network (DNN) model to make predictions about the Head Injury Criterion (HIC) in pedestrian crashes. The method combines experimental data analysis, feature engineering, and machine learning to make predictions more accurate.

A. Getting Data and Analysing Correlation

In the initial phase, dynamic stiffness measurements and their associated HIC values are obtained from controlled impact experiments. At first, a simple steel plate structure is used to look at how stiffness and HIC values are related. This baseline analysis helps us figure out if stiffness parameters can be used to predict how bad an injury will be.

B. Analysing the impact of a vehicle hood

The study first checks the basic correlation with the steel plate, and then it looks at real vehicle hood structures. To get a better idea of how the structure will behave in real life, impact tests are done on vehicle hoods. The results show that interactions between the hood and the parts of the car underneath it have a big effect on HIC values. This shows how complicated real-world crash situations can be.

C. Preparing Inputs and Feature Engineering

Multiple input features are taken from the experimental data to make predictions more accurate. Some of these features are dynamic stiffness parameters, the hood's geometric properties, the material's characteristics, and the conditions of the impact. Another parameter called penetration depth is also thought to show how the hood and lower structural parts interact during an impact.

D. Building a Deep Neural Network Model

A Deep Neural Network (DNN) is built to learn how the features that were taken out and the HIC values are related in a nonlinear way. The model has several hidden layers and is trained on data from tests of steel plates and vehicle hoods. To make predictions more accurate, the network is optimised by using the right training algorithms and tuning the hyperparameters.

E. Algorithm for estimating penetration

A specialised algorithm is created to figure out how far the hood will go into the parts of the car below it during an impact. This penetration value is added as an extra input feature to the neural network. This lets the model capture structural interaction effects that have a big effect on how bad a head injury is.

F. Testing and Predicting the Model

Finally, the trained DNN model is tested by comparing the predicted HIC values to the actual results of the experiments. The findings indicate that the proposed model can reliably forecast head injury criteria and aid engineers in assessing vehicle hood safety in the initial phases of design.

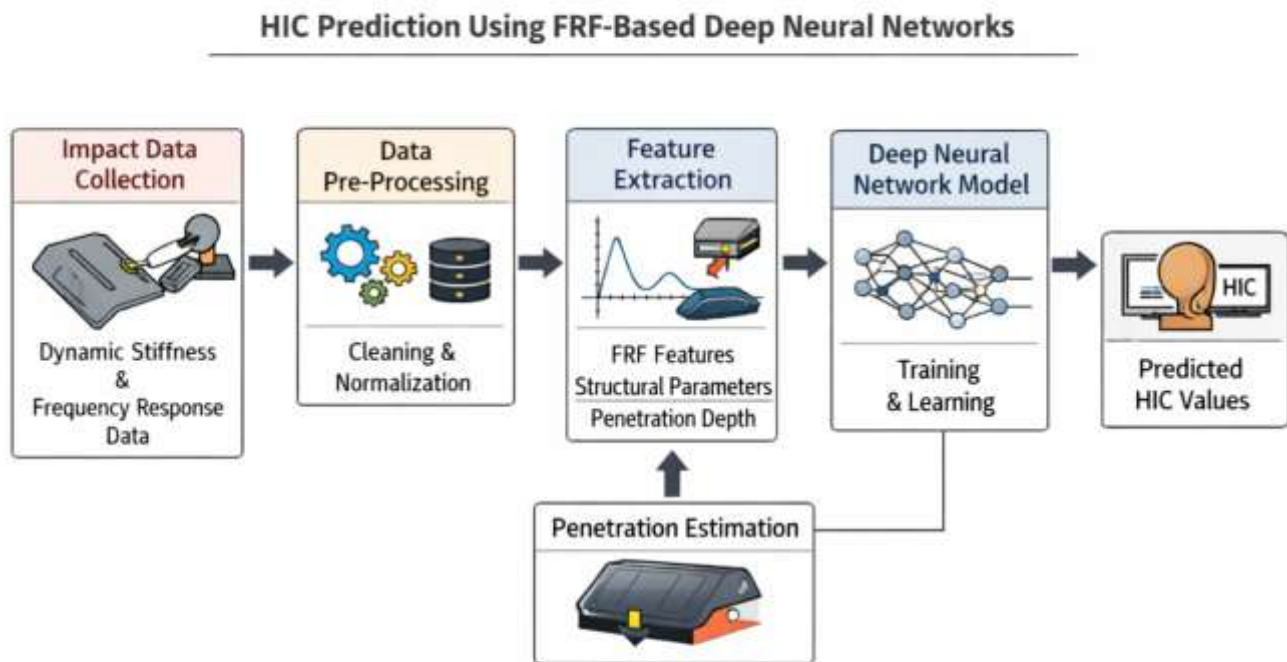
IV.SYSTEM ARCHITECTURE

There are several steps in the system architecture for predicting the Head Injury Criterion (HIC) in pedestrian crashes. First, dynamic stiffness and frequency response measurements are taken from tests on steel plates and vehicle hoods. After being cleaned and normalised, the collected data is ready for analysis. After preprocessing, important things like frequency response characteristics, structural properties, and penetration depth are taken out of the data. These features are fed into a Deep Neural Network (DNN) model, which learns how structural behaviour and head injury severity are related in a nonlinear way. Finally, the trained model predicts the HIC values, which helps us figure out how safe pedestrians are and how to make vehicle hoods better.

A. Overview

The picture shows how the system is set up to use a Frequency Response Function (FRF) based Deep Neural Network to predict the Head Injury Criterion (HIC). It begins with gathering impact data, which includes information about dynamic stiffness and frequency response. After that, the data is pre-processed and normalised, and important features like FRF parameters and penetration depth are taken out. A Deep Neural Network model uses these features to learn how structural behaviour affects the severity of injuries. Finally, the system gives the predicted HIC values that will be used to check how safe pedestrians are.

B. Architecture Diagram



V. EXPERIMENTAL SETUP

The experimental setup is meant to collect the data needed to figure out the Head Injury Criterion (HIC) in pedestrian crash situations. First, controlled impact tests are done on a steel plate structure to look at how dynamic stiffness and HIC values are related. During these tests, special sensors and measurement tools are used to record the vibration responses and Frequency Response Function (FRF) data that the impact causes.

After finding the connection with the steel plate, more tests are done on vehicle hood structures to mimic how pedestrians would hit their heads in real life. Test equipment that mimics the forces that happen when a pedestrian is hit by a car is used to hit the hood structures. To find out how the hood and its parts affect the severity of head injuries, we record how they respond.

After the experimental data is gathered, it is processed, analysed, and turned into useful features like FRF

characteristics, structural parameters, and penetration depth. Finally, these features are used as input to train and test the Deep Neural Network (DNN) model. This lets the model make accurate predictions about HIC values and helps improve the design of vehicles to keep pedestrians safe.

VI.RESULT ANALYSIS

The study's results show that the proposed Frequency Response Function (FRF) based Deep Neural Network (DNN) model can accurately predict the Head Injury Criterion (HIC) in pedestrian crash situations. The model was trained and tested using data from tests of steel plate and vehicle hood impacts. The study found a strong link between dynamic stiffness characteristics and HIC values, which supports the idea that stiffness-related factors can be used to predict how bad an injury will be.

The model's prediction accuracy improved a lot when other factors, like penetration depth and structural properties, were added as input features. The findings demonstrate that the DNN model effectively encapsulates the intricate nonlinear correlation between structural behaviour and head injury risk. In general, the suggested method is a quick way to figure out HIC values during the early design stages of vehicle development. This helps engineers make pedestrians safer without having to do a lot of physical crash tests.

VII.CONCLUSION

The research introduces a Frequency Response Function (FRF)-based Deep Neural Network (DNN) methodology to forecast the Head Injury Criterion (HIC) in pedestrian collision contexts. The findings indicate a significant correlation between dynamic stiffness characteristics derived from impact experiments and HIC values. The model can accurately predict the severity of head injuries by using these parameters along with other factors like structural properties and penetration depth.

The suggested method shows that machine learning can accurately predict HIC without needing to do a lot of physical crash tests. This method helps engineers check how safe pedestrians are when they are designing a car, and it can also help make vehicle hoods safer. Overall, the study gives automotive safety researchers a good and useful way to make sure that pedestrians are safer.

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