ISSUES IN VEHICLE TO VEHICLE CRASH RECONSTRUCTION WITH REDUCED DATA SET

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ISSUES IN VEHICLE TO VEHICLE CRASH RECONSTRUCTION WITH REDUCED DATA SET

by

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DEDICATION

यस्यामतं तस्य मतं मतं यस्य न वेद सः।

अविज्ञातं विजानतां विज्ञातमविजानताम् ॥

Yasyaamatam tasya matam. Matam yasya na veda sah.

Avijnaatam vijaanataam. Vijnaatam avijaanataam.

Those who think they know, (really) do not know.

Those who think they do not know, (really know).

Know that which is not known. Ignore what you think you know.

(*Kenopnishad, 2-3*)

I am dedicating this work to the "Almighty Lord". I am just a medium through whom he (God) aspires to bring salvation and peace to the world.

I also dedicate this work to all my teachers who have taught me about everything in and around me, through manifested and non-manifested ways.

Dedicated to my daughter *Aditri Sharma*

AUTHORS DECELARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of my thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis will be made electronically available to the public.

Sanyam Sharma

CERTIFICATE

This is to certify that the thesis entitled "Issues in vehicle-to-vehicle crash reconstruction with reduced data set" being submitted by our PhD Scholar Mr. Sanyam Sharma, to the Indian Institute of Technology (IIT) Delhi for the award of Doctor of Philosophy in Mechanical Engineering Department, is a record of bonafide research work carried out by him. He has worked under our guidance and has fulfilled the requirements for the submission of the thesis, which, in our opinion, has reached the requisite standard.

The results contained in this thesis have not been submitted in part or full, to any University or Institute for the award of degree or diploma.

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ABSTRACT

Automotive crash reconstruction is an essential part of automotive injury biomechanics. Vehicle crash reconstruction attempts to determine the kinematics of the vehicle before, during, and after the crash (also named pre-crash, crash, and post-crash phases) along with the effect on occupants in terms of injuries. With the advancement in computing at a lower cost, computer simulations of the vehicle crashes have been used extensively using Finite element vehicle models in recent years. Other approaches e.g., crash reconstruction using PC crash, was developed for vehicle pre-crash and post-crash motion simulations rather than for crash phase simulations. Multibody methods such as MADYMO can be used with crash phase simulations; however, they require detailed crash test data to model the vehicle, which is unavailable to common public for most vehicles manufactured in developing countries like India. This thesis attempts to fill this gap by proposing a method for crash simulation that incorporates crash test data from databases like Global NCAP, such as consumer rating reports and videos, in conjunction with multibody-based approach MADYMO, to simulate crash phase simulations. In order to build confidence in the proposed method, the proposed methodology was first implemented with detailed crash test data provided by the NHTSA, followed by real-world crash data provided by the NASS/CDS (In Chapters 4 and 5). 'MB-interiors and FE-vehicle' (referred here as MB-FE) coupled models were used along with proposed 'MB-interiors and MB-vehicle models' (referred here as MB-MB) simulating under the same initial condition estimates (e.g. Initial velocities of vehicles etc). These initial estimates are available for vehicle crash tests but determined using damage-based methods like Ai-damage for real-world crash data. Once it was established that both the MB-FE and MB-MB methods are comparable with one another in terms of vehicle and occupant response and also with shreds of evidence found in real-world crash data. Subsequently, this method was also implemented with the Indian RTA case (In Chapter 6), knowing that the number of unknowns is much more. These unknowns were determined from the analysis of videos and consumer rating reports obtained from GNCAP data. It was found that the MB-MB method was implementable with whatever minimal data was available. The proposed MB-MB simulation method was found to be an effective alternative for both the vehicle crash reconstruction and occupant simulations, to finally determine the occupant crash conditions (Velocities of occupants, the orientation of impact with interiors, etc.). These occupant crash conditions were further used to correlate injuries using FE human body model (the particular injuries, for which the HBM is validated previously) and FE model of interiors and interacting surfaces having correlated responses with MB interior models. This final step further strengthened the proposed methodology and checks the injury prediction capability of FE HBM in real world crash scenarios for head and chest injury.

थीसिस सार

'ऑटोमोटिव दुर्घटना पुनर्निर्माण' ऑटोमोटिव मानव क्षति (चोट) बायोमैकेनिक्स का एक अनिवार्य हिस्सा है। वाहन दुर्घटना पुनर्निर्माण दुर्घटना से पहले, उसके दौरान और दुर्घटना के बाद (जिसे पूर्व-दुर्घटना, दुर्घटना और दुर्घटना के बाद के चरण भी कहा जाता है) के साथ-साथ चोटों के संदर्भ में वाहन के अंदर बैठे लोगों पर प्रभाव के साथ वाहन की गतिकी (गति विज्ञान) को निर्धारित करने का प्रयास करता है। कम लागत पर कंप्यूटिंग में प्रगति के साथ, हाल के वर्षों में वाहन दुर्घटनाओं के कंप्यूटर सिमुलेशन का व्यापक रूप से परिमित तत्व वाहन (Finite Element vehicle) मॉडल का उपयोग किया गया है। अन्य दृष्टिकोण जैसे, 'पीसी क्रैश (PC Crash)' का उपयोग करके क्रैश पुनर्निर्माण, क्रैश चरण सिमुलेशन के बजाय वाहन प्री-क्रैश और पोस्ट-क्रैश मोशन सिमुलेशन के लिए विकसित किया गया था। MADYMO जैसी मल्टीबॉडी विधियों का उपयोग क्रैश चरण सिमुलेशन के साथ किया जा सकता है; हालांकि, उन्हें वाहन के मॉडल के लिए विस्तृत क्रैश टेस्ट डेटा की आवश्यकता होती है, जो भारत जैसे विकासशील देशों में निर्मित अधिकांश वाहनों के लिए आम जनता के लिए उपलब्ध नहीं है। यह थीसिस क्रैश सिमुलेशन के लिए एक विधि का प्रस्ताव करके इस अंतर को भरने का प्रयास करता है, जिसमें ग्लोबल NCAP जैसे डेटाबेस से क्रैश टेस्ट डेटा शामिल है (जैसे उपभोक्ता रेटिंग रिपोर्ट और वीडियो), मल्टीबॉडी-आधारित दृष्टिकोण मैडिमो(MADYMO) के संयोजन के साथ, क्रैश चरण सिमुलेशन अनुकरण करने के लिए के लिए किया गया है। प्रस्तावित पद्धति में विश्वास पैदा करने के लिए, प्रस्तावित कार्यप्रणाली को पहले NHTSA द्वारा प्रदान किए गए विस्तृत क्रैश टेस्ट डेटा के साथ लागू किया गया, इसके बाद NASS/CDS द्वारा प्रदान किए गए वास्तविक-विश्व (Real world) क्रैश डेटा के साथ लागू किया गया (अध्याय 4 और 5 में) । 'MB-इंटीरियर और FE-वाहन' (MB-FE के रूप में संदर्भित) युग्मित मॉडल का इस्तेमाल प्रस्तावित 'MB-इंटीरियर और MB-वाहन मॉडल' (MB-MB के रूप में संदर्भित) के साथ किया गया था, जो समान प्रारंभिक स्थिति अनुमानों के तहत अनुकरण कर रहे थे (जैसे वाहनों आदि का प्रारंभिक वेग)। ये प्रारंभिक अनुमान वाहन दुर्घटना परीक्षणों के लिए उपलब्ध हैं, लेकिन वास्तविक-विश्व दुर्घटना डेटा के लिए AI-Damage जैसी वाहन विकृति-आधारित विधियों का उपयोग करके निर्धारित किए जाते हैं। एक बार यह स्थापित हो जाने के बाद कि MB-FE और MB-MB दोनों विधियां वाहन और ('ओक्यूपंट'- वाहन के अंदर बैठे लोग) की 'गतिकी प्रतिक्रिया' के मामले में एक दूसरे के साथ तुलनीय हैं और वास्तविक दुनिया के क्रैश डेटा में पाए गए सबूतों के साथ भी तुलनीय हैं। बाद में भारतीय सड़क यातायात दुर्घटना मामले (अध्याय 6 में) के साथ भी इस पद्धति को लागू किया गया, यह जानते हुए कि अज्ञात मापदंडों की संख्या बहुत अधिक है। ये अज्ञात पैरामीटर जीएनसीएपी डेटा (GNCAP Data) से प्राप्त वीडियो और उपभोक्ता रेटिंग रिपोर्ट के विश्लेषण से निर्धारित किए गए। यह पाया गया कि जो भी न्यूनतम डेटा उपलब्ध था, उसके साथ एमबी-एमबी पद्धति लागू करने योग्य थी। प्रस्तावित एमबी-एमबी सिमुलेशन विधि को वाहन दुर्घटना पुनर्निर्माण और अधिभोगी सिमुलेशन दोनों के लिए एक प्रभावी विकल्प के रूप में पाया गया। अंत में अधिभोगी दुर्घटना की स्थिति ('ओक्यूपंट'-वाहन के अंदर बैठे लोग) के वेग, अंदरूनी हिस्सों के साथ प्रभाव का उन्मुखीकरण, आदि) निर्धारित करने

के लिए, इस विधि का इस्तेमाल किया गया। इन अधिभोगी दुर्घटना स्थितियों का उपयोग एफई मानव शरीर मॉडल (विशेष चोटें, जिसके लिए एचबीएम पहले मान्य है) और एमबी इंटीरियर मॉडल के साथ सहसंबद्ध प्रतिक्रियाओं वाले अंदरूनी और अंतःक्रियात्मक सतहों के एफई मॉडल का उपयोग करके चोटों को सहसंबंधित करने के लिए किया गया। इस अंतिम चरण ने प्रस्तावित कार्यप्रणाली को और मजबूत किया और सिर और छाती की चोटों के लिए वास्तविक विश्व दुर्घटना परिदृश्यों में एफई एचबीएम की चोट की भविष्यवाणी क्षमता की जांच की।

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LIST OF ABBREVIATIONS

ADAC	Accident data analysis center
ABF	Abdominal Peak Force
AIS	Abbreviated Injury scale
ANOVA	Analysis of variance
ATD	Anthropometric test devices
CAD	Computer aided design
CCIS	Co-operative crash injury studies
CDC	Collision deformation classification
CDS	Crashworthiness data system
CE	Compression extension
CEM	Crash energy management
CF	Compression flexion
CG	Centre of gravity
CIREN	Crash injury research and engineering network
COR	Coefficient of restitution
CORA	Correlation and analysis
CORA-CL	Correlation and analysis- Correlation rating
CORA-CD	Correlation and analysis-Corridor rating
CRASH	Calspan/Computer Reconstruction of Accident Speeds on Highway
CRASH3	Calspan Reconstruction of Accident Speeds on Highway (Version 3)
DaCoTA	Data, Collection, Transfer and Analysis (Road safety program by Loughborough university, UK)

Delta-V	Change in velocity vector
EBS	Equivalent barrier speed
EDR	Event data recorder
EES	Equivalent energy speed
EEVC	European Experimental Vehicle Committee
EEVC	European Enhanced Vehicle-safety Committee
Euro-NCAP	European new car assessment program
FD	Force-deflection
FE	Finite element
FE-HBM	Finite element human body model
FFC	Femur Force Criterion
FIR	First Information Report
GAMBIT	Generalized Acceleration Model for Brain Injury Threshold
GES	General estimates system
GHBMC	Global human body model consortium
GIDAS	German In-Depth Accident Study
GNCAP	Global new car assessment program
HIC	Head Injury Criteria
IGES	Initial Graphics Exchange Specification
IIT-D	Indian Institute of Technology Delhi
IRTAD	International Traffic Safety Data and Analysis Group
LL	Left lower
LPM	Lumped parameter model

LU	Left upper
MADYMO	Mathematical dynamic model
MB	Multi body
MB-FE	Multi body finite element
MPC	Magnitude-Phase-Composite (Metrics)
NASS	National automotive sampling system (USA)
NATRIP	National automotive testing and R&D infrastructure project
NCAP	New car assessment program
NCHRP 22-24	National Cooperative Highway Research Program
NCRB	National crime records bureau
NHTSA	National highway traffic safety administration (USA)
Nij	Neck injury criterion
ODB	Offset deformable barrier
ODBCT	Offset deformable barrier crash test
PDOF	Principal direction of force
PMHS	Postmortem human subjects
POI	Point of impact
RAIDS	Road accident in-depth studies (United Kingdom)
RBCT	Rigid barrier crash test
RL	Right lower
RSVVP	Roadside Safety Verification and Validation Program
RTA	Road traffic accidents
RU	Right upper

SMAC	Simulation of automotive collision
SSF	Static Stability Factor
S&G	Sprague and Geers
S&G-M	Sprague and Geers Magnitude
S&G-P	Sprague and Geers Phase
TCFC	Tibia Compressive Force Criteria
TE	Tension extension
TF	Tension flexion
THUMS	Total Human Model for Safety
TI	Traffic inspector report
TI	Tibia Index
TNO	Netherlands organization for applied scientific research
TTI	Thoracic Trauma Index
UN	United nations
US	Acronym for USA (United states of America)
VC	Viscus criterion
w.r.t.	With respect to
WHO	World health organization
WinSmash	An accident reconstruction software by NHTSA

LIST OF SYMBOLS

m, M	Weight of the vehicle
W_{Def}	Deformation work (Dissipated energy absorbed by the vehicle structures)
J	Moment of inertia about the verticle axis or Yaw moment of inertia
v_i	Translation velocity at the begening of collision
v_f	Translation velocity at the end of collision
ω	Yaw velocity at the end of collision
$\mathrm{F(t)}$	Force as a function of time
$a(t)$	Acceleration as a function of time
$E_{total}\ or\ E_A$	Energy absorbed in maximum compression or Total energy
$E_{def}\ or\ E_D$	Dissipated energy
E_R	Potential energy recovered or Restored energy
b_1	Slope of Campbell curve in speed per unit length
C_R	Residual crush
b_0	Zero crush speed (Speed at which no residual crush is observed)
C_{avg}	Average crush
e	Coefficient of restitution
C_i	Crush depth at ith position
B	Slope of Campbell curve in force per unit residual crush (C_R) (Coefficient in Campbell force model)
E_C	Crush energy
G	$A^2/2B$ = Coefficient in Campbell force model

C_M	Dynamic crush
v, V	Velocity
X	Maximum static crush
v_S	Velocity of separation
v_A	Velocity of Approach
L	Width of the vehicle
A_D	Area of damage
ξ	Slope of residual vs dynamic crush line
A	Campbell coefficient (Crush stiffness coefficient)
Γ	Coefficient in McHenry model
k_1	Loading stiffness
k_2	Unloading stiffness
ρ	Coefficient in McHenry model
γ	Maximum COR value when, $C_R \ll C_M$
$W_{Def,1}$	Deformation work for vehicle 1. (,1) For vehicle 1
α	$= C_1 + 2(C_2 + C_3 + C_4 + C_5) + C_6$,Where $C_1 - C_6 =$ Crush depths
β	$= {C_1}^2 + 2({C_2}^2 + {C_3}^2 + {C_4}^2 + {C_5}^2) + {C_6}^2$ $+ C_1C_2 + C_2C_3 + C_3C_4 + C_4C_5 + C_5C_6$, Where $C_1 - C_6 =$ Crush depths
Δv	$Delta - v$ or 'Change in velocity vector'
σ_{c1}	Crush strength of volume 1
σ_{c1}	Crush strength of volume 2