Occupant Protection and Rescue using Automotive Cyber-Physical Systems

Costin D. Untaroiu*, Jeff R. Crandall
Center for Applied Biomechanics,
Department of Mechanical and Aerospace Engineering,
University of Virginia, Charlottesville, VA, 22903,
**email: costin@virginia.edu, phone: (434) 296-7288(ext. 151)*

Background: The current trend in the automotive industry is the expanded use of embedded electronics connected to physical sensors and actuators in an effort to increase the functionality, robustness, and safety of new vehicles. Automotive safety, in an effort to prevent crashes and to protect the occupants in emergency situations, provides an ideal application for emerging innovations in Cyber-Physical Systems (CPS). The majority of current CPSs have been focused on crash avoidance with enhanced vehicle controllability and stability (e.g., automatic braking systems and traction control systems.) and driver warning systems for potentially dangerous situations (e.g. lane departure, lane shift warnings, etc.). While the active safety measures mentioned above are playing a significant role in reducing traffic accidents, the current numbers of crash-involved vehicles remains high (17 million crashes involving 28 million vehicles [1]). Thus, augmentation of existing CPS effort through improvements in occupant protection during the crash and rescue post-crash could significantly reduce the huge societal burden represented by the traffic accidents ($112 billion economic cost annually in US-[1]).

Current Technology – Crash Phase: Occupant protection during the crash is performed using active and passive restraint systems. These systems attempt to decelerate the occupant's mass safely during the crash phase, without producing injuries. Current legislative and consumer standards typically assess the injury risk of an average size Anthropometric Test Device (ATD) in a standard posture with a limited range of impact conditions. The risks of occupant injury depend on many potential variables related to the crash conditions (e.g., speed, crash direction), vehicle properties (e.g., interior parts, restraint system), and occupant characteristics (e.g. anthropometry, posture). While the current restraint systems have a very limited degree of restraint adaptation to the accidents conditions, it is expected that the safety performance of a system optimized in certain conditions to decrease in real world accident conditions.

Current Technology – Post-Crash Phase: The effectiveness of occupant rescue in the post-crash phase depends significantly on the timeliness, appropriateness and efficacy of the care service provided to accident victims. In the emergency medicine community, it is well-known that the time is crucial for trauma. The longer time the injured tissue is deprived of normal function, the greater the deterioration, and the greater long-term consequences. Thus, the goal of emergency care is to get seriously injured patients into trauma center within the "Golden Hour" [1]. Each year about 650,000 people suffer moderate to severe injuries in traffic accidents [1]. An unknown portion of these people are under-triaged (i.e. receive less than optimal care) which result in needless death and disabilities. On the other hand, over 7 million people suffer minor or no injuries in traffic accidents each year [1], of which an unknown portion are over-triaged to trauma centers resulting in an unnecessary burden on health care cost. Recently, Advanced Automatic Crash Notification (AACN) systems have been mounted on vehicles in order to transmit the vehicle's GPS location and crash-related data (i.e., velocity change and peak deceleration) to a service provider. The service provider subsequently calls an emergency call center and transmits rough estimates of injury severity determined using statistical algorithms. While a general assessment of crash and injury severity is provided, the application of this data is limited due to its lack of specificity regarding collision details, vehicle damage, and injured body region(s). It is clear that a more timely and accurate assessment of the injury severity and location would significantly improve allocation of emergency medical resources, decision-making on the appropriate level of trauma center to treat the injured occupants, and preparation of hospital equipment and facilities (e.g., surgical room prep) to handle the injuries.

Future Technologies: We anticipate that future restraint systems will be able to increase their effectiveness beyond what is currently available. Estimates of potential injury reduction using the *ideal* restraint for each collision/passenger combination range from 42% to as high as 68%. This indicates a very strong opportunity for reduction in passenger injury cost through adaptive restraint systems [2]. These systems will require accurate information about the occupant and vehicle characteristics during pre-crash and crash phases in order to choose the most appropriate restraint laws. While the information about the occupant and crash is obtained as sensor data, new CPS systems included in new restraint systems should include statistical classifiers which will analyze the data and assign a certain class for each occupant and crash. Our recent studies [3,4] using an average male model, a typical frontal crash (56 km/h), and various occupant pre-crash postures have demonstrated that the definition of the posture classes plays a major role in obtaining a good performance in terms of reducing the occupant injury cost. Since the coupled system of occupant and restraint system interaction is highly nonlinear, the injury cost and optimal classes showed a non-convex shape and a non-uniform distribution in occupant space, respectively [4]. A similar behavior is expected when other occupant characteristics such as mass, stature, and tensing are considered [2]. To move toward optimal restraint systems, there is a need for rethinking the way these systems are designed, tested, tuned, and implemented. To be able to handle and take advantage of the complexity of future automotive CPS, the occupant protection systems should communicate with the avoidance systems (called also active safety), and also transfer information to the crash injury estimators.

We anticipate that in the future, the majority of vehicles will be connected to crash notification systems. Conceptually, the simulation information that is used to optimize the restraint restraints during the crash phase could be employed in prediction of inherent unrecoverable damage (i.e., injury). This injury information could in turn be distributed to emergency medical response teams and trauma-center medical professionals to facilitate patient handling, triage and medical care.

Technical Challenges and Opportunities: The path towards obtaining an ideal occupant protection and an optimal emergency care system entails a number of significant technical challenges.

1) With continuous progress in sensor technology, it is assumed that the amount of information available to safety systems will be comprehensive in the future. Sensory systems will include

not only vehicle-based for detecting exterior obstacles but also occupant-compartment sensors to monitor the driver, restraints, and interior structures. Therefore, it will be critical to discern *which information will have utility for occupant classification and control the restraint systems*. In addition, it will be interesting to prioritize uses of the information in critical conditions (e.g. when there are delays or even loses in the information flow).

2) Since the crash event is a very fast event (e.g., about 100 ms), the *computational speed* of identification/classification and control algorithms will be crucial. Therefore, it is expected that many of these algorithms will initially be developed off-line and then embedded in new automotive CPS to be selected for a certain crash scenario [3, 4].
3) Given the number of parameters and associated ranges, it is expected that these algorithms will be obtained numerically [5]. Therefore, *development and validation of numerical models (especially human models)* used in this process will be also a crucial point toward better restraint laws and post-crash prediction.

These techniques are potentially transformative methodologies that will enable the development of optimal restraint systems for all crash scenarios and all occupants. In addition, the information that characterizes the post-crash occupant state will enable an optimal triaging and care of injured vehicle occupants. However, the success of both the protection and rescue endeavors will depend significantly on the advancements in information, computation and control of future automotive CPS.

[1] Champion, H. R., Augenstein, J. S., Blatt, A. et al. "New tools to reduce deaths and disabilities by improving emergency care: Urgency software, occult injury warnings and air medical services database". In: The *19th International ESV Conference*, 2005
[2] Bose D., Crandall J.R., Untaroiu C.D., Maslen E.H. "Influence of Pre-Collision Occupant State Parameters on Injury Outcome in a Frontal Collision", *Accident Analysis and Prevention*, 42(4): 1398-1407, 2010.
[3] Adam, T. and C.D. Untaroiu, "Identification of Occupant Posture using a Bayesian Classification Methodology to Reduce the Risk of Injury in a Collision Fundamentals", *Transport Res. C-Emer*., submitted for publication, 2011.
[4] Untaroiu, C.D., Adam T., and Maslen E.H. "Posture Classification to Reduce the Risk of Occupant Injury in a Collision", *The 2011 IEEE Intelligent Vehicles Symposium*, 2011.
[5] Crandall, J.R., "Simulating the road forward: The role of Computational Modeling in realizing future opportunities in Traffic Safety", *IRCOBI Conference*, 2009.

Dr. Costin D. Untaroiu is a Research Assistant Professor of Mechanical and Aerospace Engineering and leads the computational group at the Center for Applied Biomechanics, University of Virginia. His current research focuses on developing human body models and applying pattern recognition and optimization algorithms for occupant and pedestrian protection.

Dr. Jeff R. Crandall is the Nancy and Neal Wade Professor of Engineering and Applied Science and Director of Center for Applied Biomechanics at the University of Virginia. His research focuses on mechanisms of injury under impact loading with current research areas that include occupant and pedestrian protection.