Program Progress Performance Report for University Transportation Centers

Agency:
US DOT
Research and Innovative Technology Administration
UTC Program

Federal Grant Number:
DTRT12GUTC11

Project Title:
Technologies for Safe and Efficient Transportation (T-SET)
Tier 1 University Transportation Center

Program Director:
Dr. Raj Rajkumar
raj@ece.cmu.edu
412-268-8707

Submission Date:
January 30, 2015

DUNS Number:
05-218-4116

EIN Number:
25-0969449

Recipient Organization:
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213

Recipient ID Number:
27484.x.1080266

Project Grant Period:
1/31/2014 –

Reporting Period End Date:
December 31, 2014

Report Term or Frequency:
Semi-Annual

Signature:
1. Accomplishments

Major Goals and Objectives of the Program

Research, Development and Deployment by the T-SET UTC

The CMU-Penn T-SET UTC focuses on research, development and ultimately deployment of technologies for safe and efficient transportation. The thrusts of the T-SET UTC are structured along 5 core areas: In-Vehicle Technologies, Infrastructure Technologies, Human-Vehicle Interactions, Mobility/Data Analytics and Policy. Each of the 16 research projects has identified Year 1 and Year 2 Desired Outcomes and Metrics.

Metrics
- Number of publications and citations of faculty work in transportation-related areas.
- Number of new hires, new research initiatives, and special projects that build on intellectual leadership in fields related to the mission of the UTC.
- Research collaborations in related fields.
- Quantified impact of technology deployments and transfers.

Education and Workforce Development

Education and workforce development are important compliments of the T-SET research program.

Metrics
- Number of institutional educational partnerships
- Number of participants in workforce and educational programs
- Number of related degrees awarded at our institutions
- Number of new educational programs established
- Number of job placements through workforce development programs.

Technology Transfer

The CMU-Penn UTC will fully use the resources and experience of these university centers to promote enterprises arising from its research program. Faculty who have already created startups in the past will serve as mentors to colleagues interested in this activity.

Metrics
- Involvement of faculty in technology transfer activities:
  - Number of conferences, meetings, and formal discussions that focus on end users of ITS
  - Number of patent applications filed
  - Number of startups created
  - Number of technology licenses issued

Collaboration

Collaboration is the heart of the entire T-SET program. Carnegie Mellon and the University of Pennsylvania seek to ensure our research and development program leads to deployment of technologies in the transportation systems serving our communities and state, providing pilots applications for global use. The CMU-Penn team will collaborate with related centers on the two campuses, state and local public partners, non-profit community partners, educational partners and industry partners.

Metrics
- Number and diversity of members of the T-SET Consortium
- Number and impact of deployments achieved through collaboration

Diversity

T-SET projects will focus on transportation users in both rural areas and center cities, in suburban commuters and on residents of small communities with limited transportation options.

Metrics
- Participation by students and faculty of color and women in UTC research projects
- Projects focused on rural, city, and suburban residents
- Number of projects targeted at aging populations and persons with disabilities
Accomplishments Under the Major Goals

See Appendix A for specific research project accomplishments.

Education and Workforce Development

Below is a listing of specific additional Education and Workforce Development efforts T-SET personnel have engaged in over the past six months:

Executive Director, Al Biehler sat on a panel with Rhina Cutler, Philadelphia’s Deputy Mayor Transportation and Utilities, and Megan Ryerson, PennPlanning Professor entitled: "The Future of All Things Transportation in Philadelphia and Beyond" at UPENN

- Brought on first Women in Transportation Fellow at Heinz College, placed at Boeing for summer internship
- Growth with Intelligent Transportation Systems, Profs, S. Qian and S. Caldwell.
- Developed a Systems Synthesis Course entitled Move32: Regional Traveler Information System
- Sponsored a lecture entitled: Smartphone-enabled Urban Solutions: Mobility On Demand and Mobility On Sale featuring Shih-Fan Chang
- Faculty Seminar Series presented T-SET research to student body at three lectures
- Attended Young Professionals in Transportation Pittsburgh Chapter Meeting
- Working with PennDOT to establish summer internship program
- Started the Smart Transportation Club at CMU
- Hosted undergraduate transportation research seminar

Technology Transfer and Collaboration

Raj Rajkumar spun out Ototmatika that has built a fully functional and globally publicized fully autonomous Cadillac SUV. The company intends to become the leading vendor of advanced driving assistance and human-in-the-loop autonomous driving features to the automotive supply chain in a rapidly expanding market. Ototmatika's proprietary technology is developed by an experienced world-class team at a time of intense industry interest in advanced driving features. Ototmatika's total addressable market measures in multiple billions of dollars. To date, Ototmatika partnered with Delphi and has raised $2.5 million.

Chris Hendrickson, Carnegie Mellon University's Hamerschlag University Professor of Civil and Environmental Engineering, was elected to National Academy of Construction.

Hosted the following:
- T-SET UTC Consortium Meeting at CMU
- Pennsylvania AAA Visit to CMU for Autonomous Vehicle Demo
- CMU Smart Infrastructure Incubator Symposium
- CMU College of Engineering Research Directors Reception
- ITS America 2015 Annual Meeting Host Committee Kick-off event in Pittsburgh
- MIT Enterprise forum on Policy, Innovation and Entrepreneurship
- CMU Undergraduate Research Fair
- CMU Transportation Club Q&A with Pgh Bike Share

Presented at the following:
- KEYNOTE at The Penn State Transportation Engineering and Safety Conference
- KEYNOTE at IEEE
- Pittsburgh Mayor’s Televised Clean Tech Forum Intelligent Transportation
- Society of America Annual Meeting in Philadelphia
- ITS America Leadership Circle and Smart Cities Council conference in San Diego
- RAND
- PA State Innovation Council
- Southwestern PA Commission at Indiana University of PA
- Intelligent Transportation Systems World Congress in Detroit
- New York Association of Transportation Engineers
- Board Meeting of the Local Government Academy
- Pro Walk/Pro Bike/Pro Place Conference
- Academic Roundtable 2014
- Livability and Level of Service: Making the Connection Webinar
Attended the following:
NACTO Designing Cities Conference
WTS Pittsburgh open house
Present T-SET and Traffic21 Research to the
Attend Institute of Politics Annual Elected Officials Retreat
Ockland Task Force Meeting
Ockland 2030 District Kick-Off Event
Ockland Leadership Forum
Pennsylvania Society Annual Meeting in New York City
Allegheny Conference on Community Development Annual Meeting
Pittsburgh Supercomputing Center Commonwealth Advisory Committee Meeting
ITSMA MASITE Lunch Seminar

Held meetings with the following:
Visiting staff of the Federal City Council from Washington, DC
Mark Schlossburg of University of Oregon regarding UTREC
PennDOT and other PA Universities for planning research symposium
Meeting with the Buhl Foundation
Port Authority Bus Garage
Southwestern PA Commission on Mobility Analytics
Meeting with Liz Burket from Collins Engineering
Meeting with IBM Dublin Researchers
Meeting with PennDOT and CMU Design on local transportation improvement near campus
Meeting with Open Roads Consulting
Meeting with campus visitors from Ford
Campus Visit from Staff of the Governor’s Office to learn about Traffic21/T-SET Research
Meeting with Pittsburgh City Councilwoman Theresa Kail Smith
Meeting with Pittsburgh City Councilman Dan Gilman
Meeting with City of Pittsburgh Chief of Innovation and Performance Debra Lam
Facilitated UTC tour of Leadership Pittsburgh participants
Facilitated CMU’s Community Connections Meeting to coordinate university work with the community
Pittsburgh Supercomputing Center Meeting with PALT Governor Jim Cawley
Pittsburgh Bike/Ped Coordinator to discuss deployment
Pittsburgh Urban Redevelopment Authority to discuss deployment
Councilwoman Deb Gross’s Chief of Staff to discuss deployment
Pittsburgh Mayor Peduto to discuss parking research
City of Philadelphia Department of Public Works to discuss deployment
Michael Baker to discuss collaboration

Diversity
- Started the Women in Transportation Fellowship at the Heinz College, awarding one female incoming graduate student full tuition, placing him in a transportation-related internship and sponsoring their attendance at TRB and WTS National Meeting.
- The Women in Transportation Fellowship has been elected to the local chapter of the Women in Transportation Seminar, which is currently apply for its 501c3 status.
- Selected Dana Peck, PhD candidate, as UTC Student of the Year
- Joined WTS Transportation YOU Steering Committee with Rutgers University

2. Products
See Appendix A for specific research project products including publications, technologies, and inventions.

General Program Products
- Promotion of T-SET research news articles in weekly blog (575 subscribers)
- Weekly distribution of T-SET newsletter (630 subscribers)
- Presence on social media, 240 followers on Twitter
T-SET in the Media

Efforts have been made to promote T-SET UTC activities though the media. Below are some examples of T-SET media exposure from July-December 2014. Click on the hyperlink to view articles:

Articles:
Timed Travel: Amateur transit spotter tries to fill PAT’s real-time information void Pittsburgh City Paper
Toyota-ITC Gift Will Support Penn Research on Automotive Electronic and Computer Systems PennNEWS
Grandview traffic problems will garner extra police attention ScPghReporter
Heinz Students Break Down Barriers to Urban Development in Sule Transportation Policies HeinzCollegeWeb
Could Pittsburgh be a hub for clean technology? PittsburghBusinessTimes
Pennsylvania STICs to innovation for improved road safety USDOT Fastlane Blog
Robot Drama: Autonomous Machines in the Limelight on Stage and in Society Huffington Post
CMU-developed smart headlights help drivers cut down on glare Pittsburgh BusinessTimes
Pittsburgh Mayor Peduto Credits CMU’s UTC for Expanding Real-Time Traffic Signals Friendship Community Group Newsletter
Mazda will let you keep your high-beams on without annoying everyone PCWorld
Establishing a Robotics Fellowship at Penn Engineering’s GRASP Lab Penn Almanac
The Secret History of the Robot Car The Atlantic
Race for the Mission Viejo Council seat Orange County Register
3 Driverless Car Projects that May Change How the World Travels Government Technology
City Receives $25K from Heinz Endowments to Study LED Streetlights, Promote Energy Conservation 90.5 WESA
Pittsburgh City Council considers possible ‘dynamic’ parking pricing Pittsburgh Post-Gazette
Penn researcher studies how regional airport planners can help airports grow sustainably Penn Current
CMU Celebrates 30 Years of the Self-Driving Car 90.5 WESA
Ottonomix Raises 2.5M Pittsburgh BusinessTimes
‘Smart City’ Futurists Gather in San Diego for 1st Time Times of San Diego
Heinz Student Highlights the Future of Women in Transportation Heinz News
County, City & Pitt to build joint information infrastructure with R.K. Mellon Foundation Pittsburgh New Courier
Automakers on the road to self-driving cars atConsumer Electronics Show LA TIMES
7 Ways Self-Driving Cars Could Impact States and Localities Governing
Traffic lights on your windshield could get you home faster CNN
Looking Into The Future On Electric Vehicle Adoption Roll Call

Videos:
Deputy Executive Director Stan Caldwell Speaks at Clean Technology Roundtable (23 minute mark) - July 31, 2014

3. Participants and Other Collaborating Organizations

Hosted our Consortium meeting in Fall 2014 at Carnegie Mellon University's Pittsburgh campus, bringing together industry partners and researchers.

We continue to grow our Consortium and now have over 50 organizations.
Appendix A – Research Projects Accomplishments, Products and Participants

Safe Cyclist, Anthony Rowe, CMU

Other Dissemination Activities: Talk at "Pro Walk, Pro Bike, Pro Place" conference in Pittsburgh on 9/11/14
Talk at TSET Faculty Seminar, "What if bikes could talk to cars?" on 11/20/14
Website: http://cycchic.io; http://wise.ece.cmu.edu/redmine/projects/safebike/wiki

Other Products associated: Data & Research Material; Instruments or equipment; Physical Collections

Please explain: Photos of our experimental platform are attached as slides.

Goals & Timelines: We would like to have the database for motion tracking complete this Spring and hope to have data analysis and an initial collision alert system ready for the summer.

Multi-Modal Traffic Optimization: Pedestrian Friendly Traffic Control and Real-Time Bus Recognition Stephen F. Smith, CMU

Participant Organizations: City of Pittsburgh, Public Works Department

Other Collaborators: Citilog, Inc. (Starting in 2015)

Other publications, conference papers and presentations

Other Dissemination Activities

Technologies / Techniques: The schedule-driven intersection control approach utilized in the Surfac adaptive signal control system has been generalized to integrate sensed pedestrian traffic with vehicle traffic flows. Computer vision techniques have been adopted and extended to provide a capability for real-time recognition of buses using commercial traffic camera technologies.

Impact: Our work in pedestrian friendly traffic control expands the potential benefits of real-time adaptive signal control technologies in urban environments, and offers new opportunities for safe, efficient movement of pedestrians in the midst of vehicles. Our prior development and deployment of the Surfac adaptive signal control system has shown the ability of schedule-driven intersection control and coordination techniques to significantly reduce vehicle travel times, idle times and emissions in urban environments. Now, with generalization of the core intersection scheduling procedure to incorporate sensed pedestrians, an adaptive signal control technology can be made available for the first time that is better aligned with the multi-modal characteristics of urban traffic flows and well-matched to modern urban design concepts such as "complete streets". Our work in real-time bus recognition has demonstrated a passive means of obtaining the information necessary to incorporate bus prioritization into traffic signal control decisions, for use in settings where transit is not equipped with V-to-I communication capability.

Vehicle trust management for connected vehicles, Inseup Lee, UPENN

Other Collaborators: Nicola Bezzo, Postdoc Researcher, PRECISE Center, University of Pennsylvania

Other publications, conference papers and presentations

Website: http://precise.seas.upenn.edu/research/automotive-cyber-physical-systems/v2v/; http://www.seas.upenn.edu/~nicbezzo/UTC.html

Technologies / Techniques
1. We have proposed an optimal planning strategy against malicious attacks on stochastic cyber-physical systems (CPS). Specifically we built an algorithm that leverages the theory of Markov Decision Processes (MDPs) to determine the optimal policy to plan the motion of unmanned vehicles and avoid unsafe regions of a state space.
2. The developed technique was applied to a ground vehicle on a waypoint navigation case study.
3. We have started to work on V2V DSRC. We have recently received 3 Arada locomotive units and are learning to use them specifically to understand the communication protocol, extract and save data (like GPS data), and establish a network between the 3 devices.
4. We improved the Resilient Adaptive Cruise control algorithm studied in the previous phase of the project: specifically we created a GUI
to control the robot and visualize the measurements coming from the laser and the wheel odometry of the vehicle and extended the framework to work with any type of obstacle detection sensor (lidar, radar, kinect, etc).

Other Products associated
Audio / Video
Please explain
The video about the Resilient Adaptive Cruise Control can be found at https://www.youtube.com/watch?v=PWd6efx0v_A

Impact
1. Improve the security and safety of modern vehicular systems.
2. Improve the security and safety of highways and traffic intersections.
3. Support and train graduate students and postdoctoral researcher.
4. Release software experiment platform to support further research

Bus Turn Detection and Pedestrian Warning System, Daniel D. Lee, UPENN

Participant Organizations University of Pennsylvania, SEPTA
Other Collaborators Protran
Other publications, conference papers and presentations Intelligent Transportation Systems (ITSC), 2014 IEEE 17th International Conference on, Qingdao, China, 10.1109/ITSC.2014.6957611
Website http://www.utc.ices.cmu.edu/utc/Penn%20Reports%202013/SEPTA_report[1].pdf

Technologies / Techniques
The preliminary phase of this project will yield hardware prototypes that can be tested on a bus, using standard 12V power. The components will consist of accelerometers and gyroscopes, GPS, magnetic compass, and an embedded computer that will process and classify the incoming sensor data in real-time. The performance of the turn detection system will be detected and then used to activate a pedestrian warning system consisting of audio as well as visual warning. The log will also record impending events to assist in post-accident reconstruction.

Impact
Increasing the safety of pedestrians in Philadelphia where bus/ ped collision rate is high.

V2V cooperative formation control, V. Kumar & G. Pappas, UPENN

Other Collaborators Jack A. Stankovic, University of Virginia; Shan Lin, Stony Brook University
Other publications, conference papers and presentations Taxi Dispatch with Real-Time Sensing Data in Metropolitan Areas—a Receding Horizon Control Approach, submitted to CPSweek 2015.
Website https://sites.google.com/site/miaofeiapenn/research
Please explain A real dataset of San Francisco taxis from online open source
Impact Applying control algorithm on customer demand model learned from real-time data set, to regulate taxi supply for reducing idle driving mileage and balance the supply/demand ratio throughout the entire city.
Impact in other disciplines A framework that designs control algorithm based on basic machine learning approaches, and run simulation based on real dataset.

Proving Autonomous Vehicle & Advanced Driver Assistance Systems Safety, Andra Platzer, CMU

Other Collaborators Joao Martins, Sarah Loos, Nathan Fulton, Jan-David Quesel, Stefan Mitsch
Other Dissemination: The Logical Systems Lab presented in poster sessions this reporting period, taught an undergraduate Foundations of Cyber-Physical Systems course this fall, hosted the first CPS V&V Grand Prix undergraduate project competition and hosted a Validation and Verification: Industrial Applications and Foundations workshop (V&V) at Carnegie Mellon University this December. Poster presentations include:
Talks include:
  * Stefan Mitsch. Hybrid System Engineering. Talk at McMaster University, 9/19/2014
Website http://www.le.cs.cmu.edu
Other Products associated Models Educational aids or curricula, Software / Netware Please explain KeYmaera: The KeYmaera tool is freely available with a user-friendly, web-start version. KeYmaera is a hybrid verification tool for hybrid systems that combines deductive, real algebraic, and computer algebraic proof technologies. It is an automated and interactive theorem prover for a natural specification and verification logic for hybrid systems. KeYmaera is continually being improved with added functionality to keep up with growing research needs. We are also developing an intensive tutorial and course curricula for KeYmaera to keep up with growing demand for the tool. http://symbolaris.com/info/KeYmaera.html

Foundations of Cyber-Physical Systems Course: “Foundations of cyber-physical systems” as an undergraduate course on the formal verification of cyber-physical systems. The course introduces formal verification techniques and hybrid system modeling, with a special focus on autonomous robotics as a running example throughout the course. The course materials include a syllabus, complete lecture notes, homework assignments, lab assignments, and associated KeYmaera source code. In the Fall 2014 section of the course, students presented final projects at the CPS V&T Grand Prix to a panel of experts from industry. http://symbolaris.com/course/cps14.html

Impact Safety-critical traffic and automotive systems are becoming increasingly dependent on complex interactions with computers. Safety systems, such as adaptive cruise control, emergency braking and collision mitigation are becoming household terms, as family cars are equipped and sold with these devices. However, with the increased complexity, it is far more challenging to ensure the safe and accurate functioning of these devices, especially as an increasing number of them begin to interact on our roadways in a wide range of situations. Our research focuses on ensuring that these and other systems operate safely in all situations, even in those that are not conceived by the designers of the systems. To tackle this issue, we apply formal verification techniques, which allow us to either produce a conclusive proof that the system is safe in all situations, or provide a counter example. However, these methods are only useful if they are powerful and robust enough to verify the computers, which actually control our cars. To this end, we have developed several collaborations with people outside our field to ensure that the methods and tools we develop are increasingly applicable and useful. One such collaboration is with researchers in the Engineering department at Carnegie Mellon University. Together we are investigating how to create the right abstractions to translate systems, which are currently too complex to prove directly into provably safe systems, without lessening the strength of our safety guarantees on the original system.

In order to ultimately enable domain experts, such as traffic engineers, to ensure safety by formal verification, we develop user-friendly modeling and verification tools including tutorial and course material. The KeYmaera tool is a freely available, hybrid verification tool for hybrid systems that combines deductive, real algebraic, and computer algebraic proof technologies. Proper safe developments of transportation system designs are accompanied by a proof of correctness. Since the inherent complexities of those systems practically mandate iterative development, frequent changes of models are standard practice, but require re-verification of the resulting models after every change. To overcome this issue, we developed proof-aware refactorings that transform system models and maintain correctness proofs. We are continuing work on hybrid program refinement, but have no results to report for this period.

We developed and taught “Foundations of cyber-physical systems” (FCPS), an undergraduate course on the formal verification of cyber-physical systems. The course introduces formal verification techniques and hybrid system modeling, with a special focus on autonomous robotics as a running example throughout the course. The course was offered during the Fall 2013 and Fall 2014 terms. The course material includes lecture notes, lab assignments, homework assignments, and YouTube demonstrations for new KeYmaera users. In addition to completing the publicly available course material, Carnegie Mellon FCPS students completed an end-of-term verification project. In Fall 2014, all student projects were presented at the CPS Verification and Validation: Industrial Challenges and Foundations workshop at Carnegie Mellon University.

Impact in other disciplines Much of our research has resulted from cross-disciplinary collaborations. We have developed several collaborations with people outside our field to ensure that the methods and tools we develop are increasingly applicable and useful. One such collaboration is with researchers in the Engineering department at Carnegie Mellon University on abstraction and translation of complex systems into provably safe systems. Another collaboration is with Johannes Kepler University Linz, Department of Cooperative Information Systems. In this collaboration, we investigate how to integrate safe traffic control measures into an intermodal traffic situational awareness software framework for traffic control centers. These efforts are expected to contribute to traffic information system engineering, in order to increase safety and trustworthiness of information systems in the traffic control domain. Specifically, we contributed on modular verification techniques that enable proving a traffic network by proving properties of its components in isolation.

Bridge Monitoring, Jacobo Bielak, Hae Young Noh, CMU

Partner Organization National Science Foundation, Arlington, VA. Through grant 1130366, “Indirect Bridge Health Monitoring Using Moving Vehicles,” NSF funded laboratory and field experiments. These experiments provided the data, which we are analyzing with the UTC funding.

Collaboration We have begun working with the Pittsburgh Port Authority, we have instrumented a light rail vehicle, and have been meeting with them on a weekly basis for the last 9 months. At the core of this project, we have collaborated between Civil and Environmental Engineering (Faculty: Bielak, Garrett; Students: Ceresa, Lederman, Wang) and Biomedical Engineering and Electrical and Computer Engineering (Faculty: Kovesoev; Student: Chen). We have collaborated with Christoph Mertz from the Robotics Institute. This collaboration has allowed us to use state of the art robots in order to collect field data (dynamic response) from a parking garage structure on campus. Dr. Mertz is himself involved in other projects with the UTC. We have collaborated with Piervincenzo Rizzo from the University
of Pittsburgh Department of Civil and Environmental Engineering. Our project has benefited from Dr. Rizzo's expertise in Structural Health Monitoring. We have collaborated with Yoshinobu Oshima, an Associate Professor from Kyushu University in Japan. As a visiting researcher at Carnegie Mellon, he has assisted in analyzing the data we have collected from the Port Authority Project.

Journal publications
Acknowledgement of Federal Funding: Yes Status: Submitted

Other publications, conference papers and presentations
Thorsen, Andrew; Lederer, George; Wang, Zhao; Brelak, Jacobc; Noh, Hae Young. Mitigating the effect of variable speed on drive-by infrastructure inspection. SPIE Smart Structures/NDE 2015. 8-12 March 2015, San Diego, USA.
Acknowledgement of Federal Funding: Yes Status: Abstract Accepted

Other Dissemination Activities
- Presentation "Keeping Pittsburgh's Aging Bridges & Railways Safe," UTC Lunch Seminar by Professor Hae Young Noh, September 11th 2014.
- Presentation at the T-SET UTC Consortium Partners Meeting Aug 22nd by George Lederer.
Website [http://utc.iosc.cmu.edu/utc/projects.html]

Technologies / Techniques During this reporting period we have made progress on our deployment on the light rail system operated by the Port Authority of Allegheny County. Using only the accelerometers onboard the train, we have been able to identify areas where work has been done to correct the track geometry, as well as areas where the tracks have been replaced. This work combines some of the signal processing on graphs, developed by team members from Electrical and Computer Engineering, with the data collected and processed by the team members from Civil and Environmental Engineering. These techniques have the potential to be deployed widely on numerous types of transportation systems.

Other Products associated Databases Please explain Through our collaboration with the Port Authority of Allegheny County, we have been recording the dynamic response of a light rail vehicle for the last year. We plan to make this public when we publish our results.

Impact This reporting period, we have developed techniques to monitor track structure from a moving train in revenue service, using inertial sensors. The impact of this technology could be significant as it is widely adopted. It provides a continuous low-cost and objective assessment of the tracks, which could help flag deficiencies early making rail safer. The data could also help optimize the timing of capital replacement, which could save money. While other researchers have proposed such a system in the past, we are developing the necessary tools for analyzing the resulting data, and the first to deploy this on an operational system, having overcome many practical barriers to make our implementation successful. We are communicating these results with researchers in our field through conferences, and academic journals.

Impact in other disciplines The signal processing techniques researched under this grant continue to be published in the highest quality signal processing journals. These journals (like IEEE Transactions on Signal Processing) define the field, so our work helps to shape signal processing. Perhaps equally important, our work provides a novel application for new and existing signal processing techniques, and draws more researchers to signal processing towards solving problems in transportation and infrastructure management.

Enhancing the Safety of Visually Impaired Travelers in and around Transit Stations, M. Bernardine Dias, CMU

Participant Organizations Western Pennsylvania School for Blind Children (WPSBC), Blind and Vision Rehabilitation Services of Pittsburgh (BVRS) Other Collaborators Faculty from the University of Pittsburgh (Pitt) continues to communicate with our team on potential collaboration of our research projects on navigation and way finding for people with visual or ambulatory challenges. Faculty include Dr. George Zimmerman from the School of Education Vision Studies Program (a graduate program to prepare orientation and mobility specialists to serve the way finding and mobility needs of individuals who are blind or visually impaired), Dr. Hassan Karimi from the School of Information Sciences Geoinformatics Laboratory and Dr. Jonathan Pearlman from Human Engineering Research Labs.

Journal publications
Hassan A. Karimi, M. Bernardine Dias, Jonathan Pearsman, George J. Zimmerman; Wayfinding and Navigation for People with Disabilities Using Social Navigation Networks; EAI Endorsed Transactions on Collaborative Computing; Volume 1: 2014; p. 85. Published; Yes

Books or other non-periodical, one-time publications
1 M. Beatrice Dias, Emrine A, Teves, George J. Zimmerman, Hend K. Godewy, Sarah M. Belousov, M. Bernardine Dias; Indoor Navigation Challenges for Visually Impaired People; Hassan A. Karimi; Indoor Wayfinding and Navigation; 2015; Book; Accepted, awaiting publication; Yes
2 M. Bernardine Dias; Satish Ravishankar; Indoor Navigation Aids for Blind and Visually Impaired People; Hassan A. Karimi; Indoor Wayfinding and Navigation; 2015; Book; Accepted, awaiting publication; Yes
3 M. Bernardine Dias; The NavPal Suite of Tools for Enhancing Indoor Navigation for Blind Travelers; Hassan A. Karimi; Indoor
Top Small

Wayfinding and Navigation; 2015; Book; Accepted, awaiting publication; Yes
4 M. Bernardino Dias, Aaron Steinfeld, M. Beatrice Dias; Future Directions in Indoor Navigation Technology for Blind Travelers; Hassan A. Karimi; Indoor Wayfinding and Navigation; 2015; Book; Accepted, awaiting publication; Yes

Other Dissemination Activities On July 10, TechBridgeWorld Project Manager Ermine Teves gave a guest lecture to the Governor’s School’s Intelligent Transportation Systems (ITS) class. Ermine spoke to the students about our NavPal project and shared some of our guidelines in designing assistive technology solutions for blind and visually impaired travelers. The ITS course is supported by Carnegie Mellon University’s T-SET UTC. In August, Nicholas Haines, Omar Mustardo and Suryash Saxena presented their NavPal research as part of their respective summer programs. They collectively worked on accessible smartphone gestures and virtual navigation of unfamiliar indoor environments, as well as updating the NavPal smartphone app. On August 1, Nick and Omar gave a final presentation to their peers and the organizers of the Heinz College IT Lab Fellows program. On August 7, Suryash presented his work at the Robotics Institute Summer Scholars (RISS) Poster Session. On August 22, TechBridgeWorld team members Byung-Cheol Min presented NavPal work at a poster session that was part of the Carnegie Mellon University’s T-SET UTC Deployment Consortium Program. The poster entitled ‘NavPal: Enhancing the Safety of Visually Impaired Travelers in and around Transit Stations’ highlighted our 2014 T-SET UTC funded work as well as an initial set of design guidelines. On September 30, M. Bernardino Dias and PIT collaborators Hassan A. Karimi, Jonathan Pearlman, George J. Zimmerman had an initial meeting with members from Port Authority of Allegheny County (Breen Mascietta, Jim Ritchie and Heather Farrow) to discuss potential opportunities for collaboration. A follow up meeting is scheduled for December 18. Several times during the Fall 2014 semester, M. Bernardino Dias has had conversations with Chioko Asahawa (CMU Visiting Research and IBM Fellow, Tokyo Research Laboratory, Japan) about T-SET UTC funded work. On October 2, M. Bernardino Dias met with Guruduth S. Banavar (Vice President, Cognitive Computing, IBM Thomas J. Watson Research Center) about T-SET UTC funded work. On November 25, M. Bernardino Dias presented NavPal work at the monthly T-SET faculty meeting.

Website: http://www.cs.cmu.edu/~navpal; http://www.techbridgeworld.org; http://us2.campaignarch.com/2e2?u=4002c68a21b70084006b91&d=2048512147

Technologies / Techniques Over the past year, we have been able to study more closely the needs and challenges of blind and visually impaired (BVI) people as they navigate transit stations in Pittsburgh. Through this work, our findings indicated a strong need for a tool that allows these travelers to annotate routes with their own notes of useful information, and to easily obtain and use relevant information from trusted sources. These trusted sources can fall in the category of authorities, individuals in the area who have been vetted or have a reputation for providing trustworthy information of relevance, and personal contacts (both sighted and BVI) who the user trusts to provide useful and accurate information. The information needed and the level of detail/nature of the descriptions needed can be very different for people with different levels of visual impairment and/or familiarity of the environment. In order to further investigate the idea of this tool, we developed an Android smartphone prototype of the proposed tool. Figure 1 (see attachment) shows the system architecture and Figure 2 (see attachment) shows some screenshots of the early prototype. While Google Maps provide online map services that enable route planning, it does not provide continuous and dynamic information and notices that are often useful for BVI travelers to accomplish safe and independent navigation. In addition, it does not allow users to verbally annotate their route. This is because Google Maps does not provide a real-time map and mainly targets sighted users. As it is often crucial for BVI travelers to be informed about dynamic changes especially when traveling in unfamiliar environments and to record their observation on the changes for future trips, we developed a framework for incorporating information from trusted sources, and user annotations.

The underlying concept of the trusted source interface is that trusted individuals can share their observations about dynamic changes in the environment with BVI travelers for navigating safety and independently. For example, if a street is under renovation and a trusted individual traveling via this route observes this dynamic change that could be a potential risk to BVI travelers, then he/she can record the dynamic information through the trusted source interface. BVI travelers who have added that individual to their list of trusted sources are then alerted of this dynamic change, and can choose to avoid the street under renovation and take an alternative path to reach their destination safely. Examples of trusted individuals could be government officers in the locality, property managers (e.g., a building manager), orientation and mobility experts, friends of the BVI traveler, or BVI travelers themselves. BVI users play an important role in this methodology since the system enables them to share their personal navigational experience with other BVI users. Many BVI people prefer obtaining navigational information from other BVI persons due to having the same, or very similar, situational and informational awareness, and because of the types of descriptions and landmarks used in common.

We developed two interfaces for this prototype tool: 1) for BVI trusted sources, and 2) for sighted trusted individuals. The BVI interface of the prototyped tool is made accessible via on-screen gestures, voice commands, and audio output. Locations of interest to the user can be stored as phone contacts and effective routes between destinations (and from the current location) can be calculated via Google Maps. While navigating with this tool, the user is given audible navigational instructions at waypoint intervals, e.g., “Head north for 20 meters and then turn left.” In addition, the street name and user’s direction of travel are announced at intersections. The nearby points of interest are also automatically announced to the user for better localization and orientation. If the user deviates from the desired path at a given setting, e.g., 10 meters, the app informs the user to stop and re-routes a new path to the destination. Since on-screen gestures are a commonly used input modality for BVI users when interacting with a touchscreen smartphone, we adopted these gestures as part of our accessible interface. We first conducted a small usability study with a few BVI users from our partner networks to determine which gestures are more
effective for our tool. We also evaluated accessibility and ease of operation of our smartphone tool through this small usability study. For the annotation component, a BVI user can verbally record his or her navigational experience and refer to it for future trips using our "breadcrumb" interface which allows a user to record messages tied to specific locations on a route that will automatically be played when they encounter those waypoints in the future. Message examples include any potential hazards, a waypoint name, and orientation information for future trips. For sighted trusted users, we developed an additional app where they can simply tap the map on the screen and annotate any observed dynamic changes. Trusted users can specify attributes for the data such as 1) characterization of traversability of the waypoint, 2) the proximity of this waypoint to a key landmark, and 3) an estimated lifetime for this data to exist. The users can define a fixed lifetime in hours and minutes or can leave it as an unknown lifetime. Trusted sources data, either from BVI users themselves or sighted users, are then directly sent to the local server for storage. The data will be retrieved by the NavPal app depending on the trusted sources selected by BVI users. The trusted user interface allows BVI users to designate trusted sources for navigation aids from their contact list. This feature is vital because it enables BVI travelers to prioritize trusted users and sources and also prevents retrieval of excessive and unhelpful information. This list is stored in the user's Android internal memory and can be edited through the setting option of this interface. Finally, BVI users can be informed of dynamic changes by retrieving the user-designated trusted sources. This initial prototype was tested with four BVI users during the reporting period. User feedback confirmed the significance of its potential impact in improving safety for BVI travelers.

Other Products associated Audio / Video; Data & Research Material; Software / Netware Please explain Software: We prototyped an accessible smartphone tool ("NavPal prototype") that has significant potential to enhance the safety of BVI travelers. This tool allows travelers to annotate their paths and choose/trust trusted sources to enhance the relevant information that can enhance the safety and efficacy of their travel. Data & Research Material: Compiled and analyzed online survey data. Audio/Video: 2014 Robotics Institute Summer Scholar (RISS) Suryansh Saxena created a descriptive video about the NavPal prototype.

Impact Findings from this work are likely to impact several fields in useful ways. The needs assessment work will inform future technology development in the field of assistive technology (a subfield of robotics) and our design guidelines and prototype solutions will contribute to the state of the art in assistive technology research.

Impact in other disciplines While our focus is in the discipline of robotics, and more specifically in assistive technology, the outcomes of this work will also have impact in the fields of orientation and mobility (the specialists who train blind and visually impaired people to navigate) and human-computer interaction. Orientation and mobility experts have shown interest in how our work can assist them to further enhance the independence and safety of blind and visually impaired people. Human-computer interaction researchers who focus on interface design are interested in what we learn about accessible interfaces to technology tools through our work.

Inverse Reinforcement Learning for Car-Following. Daniel D. Lee, UPENN

Nothing to report

Distributed Transit Rider Messaging – Tiramisu, Aaron Steinfield, Anthony Tomasic, & John Zimmerman, CMU

Other Dissemination Activities
1 Team members routinely interact with interested stakeholders from industry, transit agencies, other government entities, and the general public. This ranges from meetings to discuss specific aspects of transit rider information systems all the way to acting as a resource for members of the public.
Website http://www.tiramisustransit.com

Technologies / Techniques
The team is currently focused on using intelligent software techniques to link unstructured Twitter postings about transit service to specific routes, bus stops, and vehicle trips. We are using natural language processing techniques for this effort. We are leveraging language technology toolkits popular within CMU (e.g., Carolyn Rose). These include LightSide and the Beazaar Conversation Agent Architecture. The former is a Minthand-like workbench for developing statistical classifiers and then executing them in Java. The latter is a conversational agent architecture that is used for preparing conversational tutorials. It allows one to write event recognizers and triggers, extract the information, and generate actions based on the extracted information. Once working, the gathered information will be written to a database for use by Tiramisu and other transportation systems.

We are currently in the process of determining the best training structures to draw "correct" extractions from each individual tweet. The final approach is likely to feed agency-specific information, like route short names and numbers (e.g., 89 Trafford), into automated manipulations designed to capture the most likely variations used by transit riders. Much of this data is likely to be obtainable from public agency data (e.g., GTFS). However, we feel additional information sources will probably be needed. For example, a tweet about a problem near "the Conservatory" will not link since no stops have this name in their descriptions. Utilization of a GIS source will likely be needed. While individual rules can be written, the challenge is finding an approach that is scalable to multiple cities. The team started this project late in the project year due to internal personnel schedules, so technologies and publications are not yet public.
Impact. It is still too early to judge or report on the impact of the Twitter work. During this period we also passed a Tiramisu deployment milestone. As of August, users have cumulatively made over 150,000 contributions. The system currently fuses Port Authority supplied AVL data with crowdsourced data, so we have also seen an increase in the overall user base.

Impact in other disciplines. Aaron Steinfield continues to serve on the National Academies of Science, Transportation Research Board, Standing Committee on Accessible Transportation and Mobility (ABE60). He was appointed this year to be Co-Chair of the Technology subcommittee.

https://www.myitb.org/CommitteeDetails.aspx?CMTID=1164

Anytime Computation and Control for Autonomous Systems, Rahul Mangharam, UPENN

Other Dissemination Activities
Demo and Poster at the UTC annual meeting: Anytime control and estimation in autonomous systems. P. Gurumurth, Y. Pant, R. Mangharam
Website http://mlab.seas.upenn.edu/anytime/

Technologies / Techniques
Consider an autonomous vehicle with computer vision guided flight. Fourteen cameras are sending several gigabits per second of high-order visual data to the flight guidance system. This system is perennially overloaded and must perform feature extraction, classification and estimation to provide an input @30ms to the Trajectory Controller, @300ms to the Obstacle Avoidance Controller and @50s to the Path Planning Controller. Most algorithms are run-to-completion and provide one answer upon completion and no answer if interrupted before completion. On the other hand, anytime algorithms have a monotonic increasing utility with the length of execution time. In the example above, it is important for the controller to get an approximate answer by a deadline than a complete answer later. For such overloaded data driven real-time systems, our investigation will focus on the co-design of time-bounded anytime computation and robust control algorithms to trade-off the quality of output with execution time. Given a time-varying workload, the algorithm continually measures its progress and the remaining contract time to decide its execution pathway and select system resources to maximize the quality of the result. Similarly, the robust controller instructs the computation engine on the rate and quality for processing inputs to stabilize the plant or to improve tracking. To exploit the quality-time trade-off, the focus is on the construction, instrumentation, on-line measurement and decision making of algorithms capable of efficiently managing CPU/GPU resources. This effort will enable imprecise and approximate real-time computation on parallel architectures for stream-based time-bounded applications such as autonomous vehicles, missile defense radar systems, and other overloaded high-throughput real-time systems.

Other Products associated Data & Research Material. Please explain Code for Robust MPC with discrete anytime estimation modes.

Impact. Using anytime algorithms in autonomous systems will allow us to implement flexible computation on low cost and low power platforms without violating the safety properties that are necessary for correct functioning of the closed loop system. This will allow autonomous systems to be developed without over-engineering the platform. This should lead to more cost effective platform solutions and also savings in the form of energy used for computation.

Autonomous vehicle plan verification and execution, Rahul Mangharam, UPENN

Other Collaborators. Prof. Shinpei Kato, Nagoya University; Prof. John Dolan, CMU

Other Publications, conference papers and presentations
A domain specific language and intermediate representation for autonomous driving scenarios. M.O. Kelly, T.X. Nghiem, R. Mangharam. (Submitted).

Other Dissemination Activities
1. Poster and Presentation: APEX: Autonomous vehicle plan verification and execution. PReCiSe Industry day 2014, University of Pennsylvania.
Website. http://mlab.seas.upenn.edu/apex

Technologies / Techniques. Autonomous multi-agent systems have been the focus of a great deal of research spanning the course of many years. Such systems are in high demand due to their potential to solve complex problems quickly, enable new classes of system capabilities, and reduce manpower costs. While it is possible to develop systems having high levels of autonomy, there is a lack of plan verification and validation methods for safety and performance that prevents all but relatively low levels of autonomy from being certified for use. Ensuring the safety of each scenario requires a decision control framework for plan verification and execution that interfaces tightly with sensing, online estimation, vehicle control and human intervention. Because autonomous systems are primarily implemented as software, we approach this problem through the development of rigorous software modeling and design techniques. Given this motivation, the intellectual merit of the work is on developing the modeling and verification foundations for execution of autonomous and semi-autonomous systems, which operate in real-time and with human intervention. A secondary goal is to make such formal modeling and verification available and accessible by the larger engineering community through the development of easy to use tools for describing scenarios, establishing safety properties and translating verified models to verified code.

12
Other Products associated Data & Research Material; Software / Netware Please explain Expected: Tool-chain for general representation, composition and verification of autonomous driving scenarios with multiple agents. Results from formulation and verification of standard scenarios.

Impact By increasing the confidence in the safety early in the design cycle, the broader impact of this effort will be in lowering the development cost of autonomous systems, bounding the risk of on-board software decision systems and introducing safe autonomy in a broader class of robotic systems in medical, tele-health, manufacturing and home automation.

Impact in other disciplines The proposed tool-chain and the results of the proposed research will be distributed as part of an open source framework allowing other researchers, industry, and students to incorporate findings into their projects.

Lean Control: Peak Power Minimization in Electric Vehicles, Rahul Mangharam, UPENN

Other publications, conference papers and presentations
2 Lean Control: Peak Power Reduction in Hybrid Energy Systems with Limited Load forecasts. Presented at the Predictive Control II session, American Control Conference, June 2014, Portland, OR

Other Dissemination Activities
1 Poster and Presentation: Lean Control: Peak power reduction in Hybrid Electric Vehicles with limited load forecasts. PRECISE Industry day 2014.
Website http://nlab.seas.upenn.edu/protodrive; http://nlab.seas.upenn.edu/leancontrol/

Technologies / Techniques We developed a control scheme for minimizing the peak power drawn from a costly power source in a hybrid energy system (e.g. the battery in a battery-supercapacitor energy system) given only imperfect and limited load forecasts information. The main contributions are: 1) A control scheme with two levels: a simple low-level control algorithm running at a fast sampling rate to directly actuate the plant and a more complex high-level control algorithm running at a slow sampling rate to compute optimal parameters for the low-level control to operate under a peak threshold. This architecture makes the scheme suitable for real-time implementations in systems with fast dynamics because all the complex computations are not affected by the low-level sampling rate. 2) The scheme does not require fine grained load predictions at every time step. 3) We provide a sufficient condition for controlling the Hybrid Energy System to meet the instantaneous load while satisfying a peak power threshold and other energy constraints.

Other Products associated Data & Research Material Please explain Code for simulation of control scheme with real world driving data (e.g. CMU's ChargeCar data set from: <http://chargecar.org/>). A simulink model interfaces our control scheme with the Advanced Vehicle Simulator (ADVISOR) and a matlab script is responsible for the optimization and low level control logic.

Impact Hybrid energy systems, which consist of a load powered by a source and a form of energy storage, find applications in many systems, e.g., the electric grid and electric vehicles. A key problem for hybrid energy systems is the reduction of peak power consumption to ensure cost-efficient operation as peak power draws require additional resources and adversely affect the system reliability and lifetime. Furthermore, in some cases such as electric vehicles, the load dynamics are fast, not perfectly known in advance and the on-board computation power is often limited, making the implementation of traditional optimal control difficult. In such cases, our control scheme can be used for real-time power distribution among the components of the hybrid energy system while the maximizing the lifetime/ minimizing operating cost of the system. Simulations with real world drive cycle data showed the benefits in form of a 10% reduction in peak temperature of a battery in a battery-supercapacitor hybrid energy system powering an electric vehicle. Over the long run, this would translate to a noticeable improvement in the lifetime of the costly battery system.

Impact in other disciplines The reverse problem that can be solved with simulations using our proposed scheme is the sizing problem of components in the hybrid energy system design phase, e.g., with the historic driving data and a high fidelity vehicle model (ADVISOR). Simulations with our scheme can be used to obtain a 3-dimensional surface that shows the improvement in performance (e.g., reduction in peak temperature) in the z-axis vs battery size (Ah) in x-axis and supercapacitor size (V, F) in the y-axis. This can be used to evaluate the solved the design time problem of how much capacity/cost of the components results in what saving/improvement in performances and operating points where the design becomes optimal for an average driving profile can be obtained.

Automatic Recognition and Understanding of Driving Environment for Driver Feedback, Luis E. Navarro-Serment, Martial Hebert, CMU
Technologies / Techniques The purpose of our work is to develop models of a vehicle's surrounding environment which can be used to provide drivers with navigational assistance, e.g. to generate alarms, make recommendations, or even take emergency actions. An intelligent driving assistant must be cognizant of two basic elements: 1) the environment surrounding the vehicle, and 2) the expected movements of other objects. In this effort, we have developed algorithms capable of detecting moving objects from a moving vehicle using inexpensive sensors and computing platforms such as cell phones. There are several key benefits of using cell phones for this purpose. First of all, their affordability makes them attractive to a large number of people, as opposed to existent similar products with prices in the $750-$1000 range. Secondly, smartphones typically include a standard set of sensors (e.g., camera, GPS) that can be used to implement a robust solution. Finally, smartphones provide a convenient way of accessing external sources of information, which can be used to generate priors on the set of possible object occurrences and locations.

Detecting moving objects from a moving platform is a difficult problem. Variations in camera exposure and scene illumination, and the apparent motion resulting from object shadows cast onto the road make it difficult to distinguish shadows from the object itself and therefore to identify moving objects. Also, newly-seen regions need to be labeled promptly and properly as background or a moving object. In order to boost the performance of the detector, we have developed methods for fusing Geographical Information System (GIS) data and camera data to detect moving objects. To our knowledge, the use of GIS priors has not been used before in the context of detecting moving objects in our detector, external GIS knowledge is retrieved from OpenStreetMap as the geometry of the area in a 2D bird eye view. This low-level map information describes some elements of the scene surrounding the vehicle, such as roads and buildings. Projecting this knowledge into the image space helps to reduce the search region and also to increase the accuracy of the detection. This technique is well suited for use in smartphones. Another technical innovation of this research is that our detector combines high- and low-level visual cues in a multi-layered graph cut framework. This technique provides better point-wise labeling of the scene, as shown in the sample results (see supplementary material). Additionally, we developed algorithms to assist drivers in detecting and following roads under severe weather conditions. Driving under bad weather conditions is a challenging task for the drivers. Some factors, such as invisible lane markings, full or partial snow coverage, and heavy rain cause traffic accidents. For this reason, we started to develop a robust and real-time road detection method suitable for deployment using cell phones and capable of assisting drivers. We leveraged concepts from our work in moving object detection using GIS prior information obtained from OpenStreetMap and 2D color image data to build a robust and automatic road detection technique. To our knowledge, this approach, which combines 2.5D prior information with color camera images, has not been reported in the literature for this task.

In our algorithm, two different complementary modules will help to increase the accuracy and reduce the computational time of the detection process. We implemented an existing state-of-art road detection method, which was specifically developed for detecting ill-structured roads. This method uses only visual features, such as orientation of the texture and contrast consistency in the road region, obtained from color images to identify the low-dimensional shape of the road. We tested this technique in our dataset, which includes about 3000 partially and fully snow covered road images and it showed dramatically low performance. We have also developed multi-threaded software to serve as a framework for our computer vision applications on smartphone. This framework communicates asynchronously with sensor drivers, captures the data and passes it to the perception modules for processing. It allows real-time data capturing and synchronization of multiple data sources. It was designed in a way that any vision application can be plugged easily as a module into this framework without the need of substantial modifications at the software level. Also, it offers a feature to record the data of the sensors for research purposes. The vision module, which contain the perception task to detect moving objects and the road under severe weather condition can easily be integrated into this framework. We are going to share the details of developed techniques with the community by publishing our results in conference and journal papers, as well as giving presentations. Also, we will build a project website to present the methods and provide access to non-confidential resources of the research.

Impact A driver assistance system based on the algorithms developed during our research will be able to run as an application in any smartphone without requiring any additional hardware. The affordability of such system enables a scenario in which any person could potentially download it and use it on their personal phone without having to pay hundreds of dollars for units with similar functionality. As a result, more drivers, passengers, and pedestrians could benefit from additional protection against traffic accidents. On the other hand, the novel techniques developed during the course of this research—such as using GIS priors and incorporating high- and low-level visual cues—could inspire and influence the work of computer vision researchers to apply similar techniques to other related problems.

Impact in other disciplines We believe that our work in understanding the driving environment could also potentially help to better understand the circumstances in which traffic incidents occur, thus leading to improved designs of the road network. Additionally, our research and its outcome provide a pathfinder for other application where a smartphone can be used as an assistance system that carries out an interpretation of the scene in real time. Finally, we believe that demonstrating driver assistance solutions using cell phones could motivate Electronics and Chip Design Engineers to produce specialized on-board image processing hardware for smart phones. Therefore, research activities will increase in that field.

Sensory Augmentation for Increased Awareness of Driving Environment, John M. Dolan, CMU
Website http://www.rs.cmu.edu/research_project_detail.html?project_id=651&menu_id=261
Technologies / Techniques We have explored the use of automotive-grade LIDAR for the detection of road boundaries. This technique can provide lane centering information in the presence of certain boundary types (guardrail, jersey barrier, tunnel) and could be combined with other sensory input for road boundary detection under more difficult conditions.

Other Products associated Software / Netware Please explain We have created a Matlab implementation of LIDAR-based road boundary detection and are in the process of porting it to C++ for testing on our autonomous Cadillac SRX vehicle.

Impact The developed techniques make it more cost-effective to provide sensing for autonomous and semi-autonomous vehicles for road boundary detection.

Smart Automotive Headlights for Safe Driving, Srinivasa G. Narasimhan, CMU

Participant Organizations Intel, Ford Motor Company, National Science Foundation, Office of Naval Research

Other Collaborators Engaged with James Hoe in ECE at CMU to begin next hardware developmental stages for the project.

Journal publications We are currently preparing a journal submission for SPIE's Journal of Micro/Nanolithography, MEMS, and MOEMS.

Other publications, conference papers and presentations

Other Dissemination Activities An indoor demonstration of anti-glare headlight application was performed for the UTC consortium and various other visitors. Outdoor demonstrations were given to several participant organizations. The project garnered significant media coverage following a CMU press release.

Website http://www.cs.cmu.edu/smartheadlight/

Technologies / Techniques The headlight consists of three main components: a camera to observe the environment, a processing unit that analyzes the captured imagery and a spatial light modulator that controls the headlight beams in space and time for the required task. We have built the spatial light modulator, which is capable of illuminating the scene at 1700 Hz. The system software is highly optimized for low latency data management, image processing, and component control.

Impact A prototype of a novel adaptive headlight design has been developed. The reaction time of the headlight (>500 Hz) permits many tasks to help improve and enhance driver vision. The versatility of the single hardware headlight design opens the door for many applications through software. Further development of the prototype towards incorporation into vehicles is a long term goal that is certain to reduce crashes and improve driver safety.

Impact in other disciplines The headlight design has the potential to be useful in infrastructure CPS, computer vision, and computational photography.

Continuous Road Surface Distress Detection, Christoph Mertz, CMU

Participant Organizations City of Pittsburgh, Cartegraph

Other Collaborators PennDOT is funding a project with us to use the road monitoring techniques to detect snow cover on roads to determine road conditions live from snow plows.

Other Dissemination Activities Presented project to various industrial and government visitors. Presented project to Pennsylvania Turnpike Commission for possible future collaboration. Presented project to Transportation Class at CMU.

Website http://www.iit.cmu.edu/person.html?person_id=670

Technologies / Techniques The two main technologies and techniques we have developed are 1. data collection system for android smartphones and 2. image analysis algorithm to detect cracks in roads. 1. is shared with the public through a open source repository website. 2. Image analysis algorithm is shared through a conference paper publication. In the very near future more code will be made public through open source repository.

Invention / Patent applications / Licenses Open source license for some of our software.

Other Products associated Databases; Software / Netware Please explain We are continuously collecting more road data to develop and test our system.

Impact Within the discipline of Robotics and computer vision: Expand the field to include transportation research, expose students to transportation research. On the reverse, computer vision is being introduced into the field of transportation and maintenance. With the arrival of smartphones it has become easy and cost effective to collect large amounts of images and tag them with GPS and other
information. Up to now only a few companies with large financial resources were able to create city wide databases of images (e.g. Google Streetview). With such data bases new "big data" research will be possible in the fields of computer vision and transportation.

**Impact in other disciplines** There is some initial interest from civil engineering to use our results to better understand and predict the deterioration of pavements

**Regulation of autonomous vehicles, Megan Ryerson, UPENN**

**Participant Organizations** Resource Systems Group supplied some data (for free) that I am working with in support of this research

**Other Collaborators** MCP Students: Matt Discenna, Chi Zhang

**Other publications, conference papers and presentations** Presentation by Megan Ryerson at the American Collegiate Schools of Planning 56th Annual Conference in October 2014. Title: Planning Future Intercity Transportation Infrastructure Today: Incorporating Autonomous Vehicles in Air and High-speed Rail Planning

**Website** [http://www.meganryerson.com](http://www.meganryerson.com)

**Impact** With my current dataset and a dataset which I am collecting currently, I am starting to analyze how people might choose AVs over other intercity modes. AVs have the potential to completely change the mode split in intercity transportation but this is not well understood. AVs potentially have major implications for how the intercity transportation is planned and funded. My research will help federal decision makers understand how they should best direct intercity transportation investments in a future transportation system with AVs, based on people’s behavioral and travel preferences.

**Impact in other disciplines** This work delves deeply into behavioral and economic modeling. It has major impacts in the field of urban and interregional planning, transportation systems engineering, and the business of new technologies.

**Automated Detection of Objects in Rear Camera Images, Vijayakumar Bhagavatula, CMU**

**Other Collaborators** Dr. Shayok Chakraborty

**Website** [http://users.ece.cmu.edu/~kumar/](http://users.ece.cmu.edu/~kumar/)

**Technologies / Techniques** This project is in the area of computer vision for automotive safety applications. At present, we are using background subtraction algorithms (using Gaussian Mixture Models and Robust Principal Components Analysis) to learn a robust background model in order to detect the presence of objects (foreground), which do not fit the background description. We also plan to use machine learning algorithms to train a classification model to detect ground surface, pixels in the last image, which are not classified as ground surface, indicate the possible presence of objects. We further intend to develop a framework to fuse the information from the two sources in order to develop a more robust object detection system.

**Impact** A system which can robustly detect the presence of objects in rear-camera images has significant potential in reducing the number of backover accidents.

**Impact in other disciplines** The proposed framework can be viewed as a generic object detection system. It can also be used in several other applications including security and surveillance to detect abandoned or removed objects in airports and other public places.

**Automated video-based traffic count analysis, Camillo J. Taylor, UPENN**

**Participant Organizations** Delaware Valley Regional Planning Commission

**Other Collaborators** PhD Student: Ryan Kennedy, M.S. Students: Yu Yu Ting, Takeshi Furuya

**Other publications, conference papers and presentations** Appeared in ITS World Congress 2014

**Website** [http://www.cis.upenn.edu/~ctaylor/home.html](http://www.cis.upenn.edu/~ctaylor/home.html); [https://github.com/takfuruya/](https://github.com/takfuruya/)

**Technologies / Techniques** Under this thrust we have been studying the problem of video motion analysis and in particular its application to tracking and counting vehicles. To this end we have proposed new algorithms which analyze video data by tracking discrete feature points and then aggregating those tracks into groups which correspond to individual vehicles. We have reported on this work and made our source code available. We have also been working on novel algorithms for video motion analysis and we have proposed a new algorithm that models the optical flow in an image sequence using a set of triangular facets. This approach allows us to cleanly model occlusion effects. We have also shown how to integrate information from multiple frames to significantly improve the quality of the flow estimates. These methods have been tested on publicly available datasets and have been shown to provide state of the art results. These results are reported in our EMMCVPR 2015 paper.

**Other Products associated Software / Netware Please explain** The software that we have been developing has been made freely available. The link was publicized in our ITS 2014 paper.
Impact The work that we have been doing on video motion analysis has lead to the best results published so far on the challenging MPI-Sintel dataset. Our goal has been to advance the state of the art in video motion analysis and to take what we have learned and apply it to video based tracking problems. Our current work explores how global optimization schemes based on a hierarchical segmentation of the image can improve tracking performance in situations where the motion between frames is quite large. This work also suggests ways for developing schemes that simultaneously address the problems of image segmentation and motion analysis.

Planning for Autonomous Vehicles, Erick Guerra, UPENN

Participant Organizations Delaware Valley Regional Planning Association, 15 other MPOs have participated in interviews
Other Collaborators Megan Ryerson, Assistant Professor of City and Regional Planning, Upenn; Liming Wang, Assistant Professor of City and Regional Planning, PSU Master’s Students: Zachary Billet, Chi Zhang, Matt DiCenna

Other publications, conference papers and presentations Presented at 2014 conference of the Association of Collegiate Schools of Planning. Accepted for poster session at Transportation Research Board 2015 annual meeting. Presented at 2014 Delaware Regional Valley Planning Commission’s Futures Group. Contracted for 800 word article in Planning Magazine
Other Dissemination Activities Presented findings at courses at Upenn and Drexel.
Website http://utc.cas.msu.edu/utc/

Impact Findings from this study have the potential to provide guidance for researchers interested in influencing planning efforts around autonomous vehicles, illuminate some of the challenges of preparing for technological shifts, and demonstrate some of the limitations of long-range planning. Long-range planners have expressed interest in learning more about how other metropolitan planning organizations are addressing challenges associated with planning for autonomous vehicles.

Detecting Driver Distraction, Maxine Eskenazi, CMU

Participant Organizations Yahoo! Inc.
Other Collaborators Alan W Black, Tim Keller

Other Dissemination Activities Informal presentations at Yahoo! meetings, presentations to CMU visitors
Website http://www.utc.cas.cm.edu/utc/projectitem.asp?ID=97

Technologies / Techniques We are beginning to use the data we have collected to train automatic distraction detection software. This work is presently ongoing.
Please explain This project has produced two products this year: 1) driving simulator linked to Wizard-of-Oz - software is publicly available
1) data from driving simulation: this is a set of time-synced data that included video and speech, all actions of the simulator and of the Wizard-of-Oz and is also publicly available.

In-Situ Monitoring of Driver Workload, SeungJun Kim, CMU

Other Collaborators Core members: Prof. Aniruddha Dey and Dr. Jaemin Chun (CMU, HCI, Ubicomp Lab)
- Adjunct members: Prof. Aaron Steinfeld (CMU, RI), Prof. Iain Oakley (UNIST, Interactions Lab, South Korea), and KyungTaek Lee (KETI, South Korea)
- Research Assistant / Interns: Jaewon Kim (CMU), Hrmanshu Zade (Kern Communications, formerly, IIIT Hyderabad), and Divya Suresh (Coinmate Institute of Technology).

Journal publications

Other publications, conference papers and presentations
Cognitive Load based on Psycho-physiological Measures for Younger and Elder Adults. 2014 IEEE Symp. Computation Intelligence (IEEE SSCC '14; accepted).

Other Dissemination Activities Conference calls with an industry, TAKATA - Stefanie Esers (Director Global Research, HMI / Human Factors, Germany) & Matt Troup (Engineering Manager, Vision Algorithms, TAKATA Pittsburgh, TK Holdings Inc. Electronics)

1 Sep 05, 2014 – Topic: “Driver Workload Assessment in Human-Vehicle Interaction Projects”
2 Sep 25, 2014 – Topic: “Driver Workload and Interruptibility” (a follow-up meeting)

Notes: A research agreement with TAKATA is currently in progress.

Website: http://utc.ices.cmu.edu/utc/projectitem.aspx?ID=92

Technologies / Techniques
1 In-situ driver interruptibility detection technology (real-time capability: more than 94% accuracy at 1-second rate; See Figure 1)
2 Feature generation technology for machine learning applications (specifics: OBD, body motion, bio-signal; See Figure 2)
3 User-interactive visual-analytic technology for time-series sensor data streams (See Figure 3)

Impact Presents quantified implications of the driving situations and driver states when drivers consciously or subconsciously engage in peripheral interactions (i.e., actions not related to the primary task of driving the car). Demonstrates the feasibility of creating a sensor-based model that can detect opportune moments for drivers to attend dual-task demands using both the user's physiological features and features of the driving scenarios themselves (substantial impact on reducing inopportune co-occurrences of secondary tasks while driving). Presents the ecological validity of the time-series sensor data that was collected during naturalistic driving and reports a rich set of collected features for creating classifiers.

Impact in other disciplines. Has an impact in human-computer interaction domain and ubiquitous computing domain, especially on automotive UIs during field driving' research and 'interruption' research respectively. Presents an enabling technology that helps us to detect appropriate breakpoints for prompting drivers to participate in experience sampling while driving, which will support others doing driving-related research in naturalistic driving situations. Presents a compatible real-time solution to identify appropriate interruption times that a driver is available to safely split his/her visual attention and manage cognitive demand in an automotive context.