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 has already created startups in the past will serve as mentors to colleagues interested in this activity.

Metrics
- Involvement of faculty in technology transfer activities.

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

Approximately 20 township managers form the Pennsylvania LTAP Advisory Board came to CMU to learn about the work UTC is doing. Chris Hendrickson presented on our work with PennDOT and the Autonomous and Connected Vehicle Vision 2040. Christoph Mertz showed LTAP around the NavLAB and discussed his upcoming project with PennDOT: Road Surface detection.

Yeganeh Mashayekh, CMU EPP, was awarded BEST STUDENT PAPER by the Transportation & Development Institute of the American Society of Civil Engineers (ASCE) and Stantec, for her paper "Benefits of Proactive Monitoring of Traffic Signal Timing Performance Measures – Case Study of a Rapidly Developing Network."

T-SET UTC designed and taught an elective course on Intelligent Transportation Systems for the Pennsylvania Governor's School for the Sciences. These are gifted rising senior high school students with and interest in science.

T-SET Director, Raj Rajkumar presented a session on Autonomous and Connected Vehicles at ITSPA's 10th Annual Workshop and Conference.

T-SET Director, Raj Rajkumar travelled to Kyoto, Japan to present on "Intelligent Transportation with Cyber-Physical Technologies" at the 37th Annual International Computer Software & Applications Conference (COMPSAC) in Kyoto, Japan on July 23.

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

- New class at CMU, Growth with Intelligent Transportation Systems, Profs R. Hampshire, S. Qian.
- Developed a Systems Synthesis Course entitled: Almono Site Transportation Planning
- Co-sponsored a Donald Shoup, author of The High Cost of Free Parking, lecture with Pittsburgh Downtown Partnership
- Faculty Seminar Series presented T-SET research to student body at three lectures
- Met with Tepper student project group to discuss transportation issues
- Attended Young Professionals in Transportation Pittsburgh Chapter Meeting
- Participated in RITA Workshop in DC: ITS PCB University Workshop
- Guest lecture on UTC in CMU class: Design and Policy for Humanitarian Impact
- Working with PennDOT to establish summer internship program
- Working with CMU legal to be able to place students in externship program
- Developing a T-SET UTC student club

Technology Transfer and Collaboration

T-SET Director, Raj Rajkumar, testified at The House Transportation and Infrastructure (T&I) Subcommittee on Highways and Transit hearing on How Autonomous Vehicles Will Shape the Future of Surface Transportation

The Pittsburgh International Airport invited the UTC faculty out for a site visit to explore how to make it the most intelligent airport in the world. Fourteen researchers met with Operations, Security, Maintenance, and Parking managers to learn about the real-world problems they face day to day. The site visit concluded with a round table discussion and plenty of ideas for intelligent transportation solutions.

PennDOT took T-SET researchers out in the bucket and under a bridge to demonstrate their existing bridge inspection protocol. CMU researchers Christoph Mertz and Haeyoung Noh are working on bridge structural monitoring technology that includes sensors and signal processing.

T-SET hosted the Pittsburgh Bus Rapid Transit Stakeholder Advisory Committee meeting. The Committee reviewed their site visit to Cleveland and determined next steps. More about BRT and the project here: http://gettherepgh.org/press-room/

AI Biehler, Executive Director of T-SET UTC, went to Tokyo to attend the ITS World Congress. AI moderated two panels at the Congress: Transport Policy Issues and Social Benefits & Planning.

T-SET provided a 33 mile autonomous vehicle ride through congested traffic and highways for Congressman Bill Shuster and PennDOT Secretary Barry Schoch.
T-SET Hosted the following:

- T-SET UTC Advisory Council Annual Meeting
- UTC presentation to visiting Japanese Delegation
- Presentation by Don Shoup on Smart Parking and the Pittsburgh Downtown Partnership and CMU class guest lecture
- Launch CMU tour of Nav Lab
- Pro Walk/Pro Bike Transportation Summit
- Presentation of UTC Research to Visiting Denver Chamber Group

Attended the following:

- ITS Connected Vehicle Public Meeting Moving from Research Toward Implementation
- PennDOT Connected and Autonomous 2040 Vision Workshop
- Engineers Society of Western PA Champions of Sustainability Conference
- Oakland Transportation Management Association Transportation Fair
- ITS America Leadership Circle Workshop
- Congress on Connected Communities Annual Legislative Session
- Southwestern PA Commission Public Participation Panel
- PennDOT State Transportation Innovation Council Meeting
- Penn State Transportation Engineering and Safety Conference
- Pennsylvania Society Annual Meeting
- Remaking Cities Conference
- PennDOT LTAP Community Advisory Committee
- Alpha Lab Demo Day
- Allegheny Conference on Community Development Annual Meeting
- AUVSI Networking Event
- University of Pittsburgh Institute of Politics Elected Officials Retreat
- IBM Meeting on Connected Communities
- Heinz Breathe Workshop
- Atlanta Regional Chamber Visit
- Fuel Freedom Foundation Visit
- Presentation to IEEE Symposium on Embedded Systems for Real Time Media
- Presentation at APTA Annual Meeting
- Presentation to Federal Highway Administration
- Presentation to USDOT RITA Innovation Series
- Presentation to Second International Conference on Transportation Information and Safety
- Presentation to 10th ACM International Workshop on Vehicular Internetworking, Systems, and Applications
- Presentation to 3rd International Workshop on M2M Technology

Held meetings with the following:

- PA State Representative Jerry Stern's Office
- Congressman Bill Shuster's Office
- PA Governor's Staff
- Pittsburgh City Councilman Dan Gillman to Discuss Adaptive Signal Research Deployment
- CDM Smith on PennDOT Autonomous Vehicle Research
- Pittsburgh Community Reinvestment Group
- Pittsburgh Mayor Bill Peduto Transition Team
- City of Pittsburgh and IBM to discuss Smart City Deployment
- PA Chamber of Commerce Transportation Meeting
- Pittsburgh Mayor Transition Team Subcommittee on Big Data
- ITS America Staff on Big Data Research
- Pittsburgh Super Computer Advisory Committee
- PennDOT to discuss faculty research in transportation modeling
- Indiana University of Pennsylvania to discuss research collaboration
- Greater Pittsburgh Non Profit Partnership
- PennDOT to deploy UTC research on snow plows
- State Senator Wayne Fontana
- 10,000 Friends of Pennsylvania
- Washington and Jefferson College to discuss research
- AECOM to discuss collaboration
- Benedum Foundation
- State Senator Jay Costa
- Almono Development Group
- Pittsburgh Parks Conservancy
- ITS PA Annual Meeting
- Parking Authority of Pittsburgh
- Pittsburgh Airport Authority
- Bike Pittsburgh
- Hillman Foundation
- Southwestern PA Community Profile meeting
- Dave Ruppersberger, CMU/Pitt Technology
- Steve Wray, Executive Director of the Southeastern Pennsylvania Economy League
- FISA Foundation
- Barry Maciak, World-Class Industrial Network, LLC
- Directors and Developers Network

Diversity

- Joined TRB's Women's Issues in Transportation Committee
- T-SET researcher, Bernardine Dias, was awarded the 2013 Celebrating Women! Having Global Impacty by the Women and Girls Foundation
- Women in Transportation Fellowship Carnegie Mellon University's H. John Heinz III College, in partnership with the Traffic21 Initiative and the T-SET University Transportation Center (UTC), is pleased to announce the creation of the Women in Transportation Fellowship value of $80,000 for one student.
2. Products

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

General Program Products

- Feature article in USDOT's UTC in the Spotlight
- Promotion of T-SET research news articles in weekly blog (552 subscribers)
- Weekly distribution of T-SET newsletter (810 subscribers)
- Presence on social media, 154 followers on Twitter

T-SET in the Media

Efforts have been made to promote T-SET UTC activities through the media. Below are some examples of T-SET media exposure from July-December 2013. Click on the hyperlink to view articles:

Articles:

CMU's East End traffic effort turns to pedestrian safety, Pittsburgh Post Gazette
Carnegie Mellon University spinoff targets traffic flow, Pittsburgh Tribune Review
App that helps disabled use sidewalks and transportation, The Tartan
Driverless cars predicted by end of decade, Politico
Researchers Improve Transportation Safety, The Tartan
Main Roads needs to get out of slow lane, The West Australian
Driverless cars for the Road Ahead, The Wall Street Journal
New Tracking System Allows P1 East Busway Riders to See Actual Arrival Times, Waits, WESA
Assessing the impacts of Connected and Autonomous Vehicles, Move Magazine
Will Government Regulation Crash Driverless Cars, Daily Caller
Will your car be driving itself by 2020?, CBS
Vehicle of future forgoes the driver, Pittsburgh Tribune Review
Bill Shuster; Driverless cars are 'the future of transportation', Politico
Safety Groups Buzzing About Crash-Proof Car, Occupational Health and Safety
Who's that behind the wheel? Nobody, Reading Eagle
Congressman hitches a ride in a stealthy self-driving Cadillac, The Verge
PennDOT chief, U.S. congressman to make Western Pa. trip in driverless vehicle, Pittsburgh Tribune Review
Driverless Cars and Other Goodies, National Journal
The future is happening in Pittsburgh, Carpetbaggery
Carnegie Mellon developing driverless car of the future now, Pittsburgh Post Gazette
This Is What It's Like Behind the Wheel of a Driverless Car, Slate
CMU, General Motors partner on 'vehicle of the future', Pittsburgh Post Gazette

Videos:

Smarter Traffic Signals Can Save Time and Money, Inside Science
A Car That Drives Itself, CBS
Rep. Bill Shuster travels to Pittsburgh International Airport in driverless car, WTAE
At CMU cars drive themselves and the rest of us may get them soon, Pittsburgh Business Times
Driverless car steering course to road, Reuters
3. Participants and Other Collaborating Organizations

In September 2013, T-SET hosted its advisory committee for a day-long strategy meeting. In attendance were Doug Foy, Mike Meyer, Bill Millar, Jim Misener, John English, Gerry Mooney, Charles Hammel.

We continue to grow our Consortium and now have over 40 active partners.

Appendix A – Research Projects Accomplishments, Products and Participants

Thrust Area #1 In-Vehicle Technologies for Safety

Sensory Augmentation for Increased Awareness of Driving Environment  Lead: John M. Dolan (CMU)


Website: http://www.ri.cmu.edu/research_project_detail.html?project_id=776&menu_id=261

Technologies and Techniques: This project investigates safety verification of autonomous driving behaviors. Our work to date uses reachability analysis to compute the set of all possible behaviors of an autonomous vehicle. A reachable set is the set of states a system can possibly reach for a given set of initial states, disturbances, and sensor noise values. We consider autonomous vehicles which plan trajectories for a certain look ahead horizon which are followed using feedback control. While a perfectly followed trajectory might not violate specified safety properties (e.g. lane departures or vehicle collisions), there might exist a violating deviation from the planned trajectory. Given the mathematical model of the controlled vehicle and bounds on uncertainty, our approach detects any possible violation. In addition, the approach provides results faster than real time such that maneuvers of vehicles can be checked before they are fully executed.

Other Products: This project will develop robust autonomous freeway driving behaviors that build on lessons learned in the Urban Challenge, but have the following additional capabilities: freeway-speed performance; distance keeping with entrances and exits; high-density traffic lane selection and merging; reasoning about sensor confidence, degradation, and failure; and accommodation of human-in-the-loop interaction.

We have developed computationally lightweight and responsive sensor fusion-based heuristics for automotive-grade radar and relatively low-cost LIDAR that provide good situation awareness in various traffic situations, including lane change and turning into and against traffic.

Impact on the Development of the Principal Discipline: The developed techniques make it more cost-effective to provide sensing for autonomous and semi-autonomous vehicles for traffic awareness.

Task List: The project is complete as of Dec. 31. The targeted tasks were completed.

Goals and associated timeline for deploying this technology: During 2014, we will continue to refine the radar-LIDAR sensing technology and continue to test it in increasingly difficult and uncertain highway and urban traffic situations.

Automatic Recognition and Understanding of the Driving Environment for Driver Feedback  Lead: Luis E. Navarro-Serment (CMU)

Publications: Presentation - Master Speaking Qualifier Author(s): Jifu Zhou Title: Incorporate Map Priors for Outdoor Scene Understanding Journal: Volume: Year: Page numbers: Status of publication (published, accepted, awaiting publication, submitted, under review, other): Presented on Tuesday 09/03/2013 Acknowledgement of federal support (yes/no): yes

Technologies and Techniques: We have developed algorithms that use prior knowledge for scene understanding purposes. Specifically, we produced a system that retrieves map information from an external database, systematically handles the positional uncertainty of sensors and vehicles, and incorporates probabilistic distributions of this information into semantic labeling algorithms using vision. These algorithms build representations of the environment where the vehicle is operating, thus providing contextual information that describes if and where certain objects are likely to occur in the scene. These representations are used to obtain a prior
on the set of possible object occurrences, object locations and scenes. The advantage of using prior distributions obtained from external sources of information is that they can be used to place constraints on the predictions generated by other scene understanding algorithms, thus improving the accuracy of their predictions. Therefore, any previous knowledge can contribute to increasing the performance of scene understanding systems. This claim is supported through a series of experiments using actual sensor data obtained from moving vehicles. Additionally, we have produced software to extract information from external sources and generate prior distributions of objects and places in the vicinity of a vehicle. This software has allowed us to test the algorithms developed in this effort for automotive applications using data from real world situations. We plan to make this software publicly available in the future.

Other Products: We have produced an experimental evaluation of performance, which can be used as a baseline for testing new approaches in the future.

Other Organizations Involved as Partners: We have officially started a collaboration with researchers from TK Holdings Inc. We negotiated and signed a NDA. We have already received from them a large amount of data (several TBs), collected from one of their automotive sensors. We have been using to test our algorithms using a sensor which is tailored to vehicular applications, using real data collected under multiple traffic conditions. Similarly, they will explore the possibility of embedding our algorithms into one of their systems, to enhance its current capabilities. We will continue to pursue this collaboration and expect it to bear fruit in the near future.

Impact on the Development of the Principal Discipline: Within the discipline of Robotics and Machine Learning: 1) Developed algorithms for scene understanding that use external sources of information for automotive applications. 2) Exposed students to issues involved in the design of machine perception algorithms in the transportation domain.

Goals and associated timeline for deploying this technology: We are currently working on an implementation of our system using a smart camera. We plan to use this as a proof of concept that can be used inside a car. We expect to complete this implementation during the first half of 2014. Development of a prototype can be started during the summer of 2014.

Virtual Traffic Lights for Safer Intersections Lead: Ozan Tonguz (CMU)


Website: http://utc.ices.cmu.edu/utc/Tonguz%20project%20description.pdf
www.ece.cmu.edu/~tonguz

Technologies and Techniques: 1-One technique that has emerged from my project is to design Virtual Traffic Lights in a holistic manner which comprises the following aspects: i) Handling the partial penetration problem associated with DSRC technology ii) Designing technologies that can accommodate the presence of pedestrians and cyclists on the road when VTL is implemented; iii) Fail-safe design of VTL technology iv) The government policies that will be necessary for successful deployment of VTL; v) Handling the challenges posed by RF propagation at intersections due to obstructions at the corners (such as buildings, foliage, etc.) vi) Challenges posed by different faults such as GPS inaccuracies etc. vii)Making VTL design resilient against security attacks Our efforts and experiments have clearly shown that these different aspects and the design of these different components are tightly coupled and one
cannot design a commercially viable product if any of these components is ignored or overlooked. 2-A technology that has emerged from our efforts is implementation of VTL on Android-based smartphones. A substantial amount of code is already written for this and we are currently testing and debugging the code before releasing it. This is quite significant as Google has recently announced that they are pushing for Android to be the OS for the connected vehicles initiative. Several car manufacturers have already signed on to this initiative.


Other Products: 1- SOFTWARE: Large-scale simulator based on a modified version of the SUMO simulator was developed to quantify the benefit of the proposed VTL scheme in the city of Pittsburgh during rush hours (both morning and evening rush hours). A number of modifications have been made in the past six months to make the simulations more realistic. The simulator used is based on the open-source simulator SUMO (originally designed at ETH Zurich) with custom designed modules added to implement our VTL algorithm. The results obtained show that the average commute time of urban workers in Pittsburgh can be reduced by more than 35% which is quite significant. Interestingly, some of the algorithms developed on VTL was also used by European researchers at the University of Innsbruck in Austria and Karlsruhe Institute of Technology in Germany. For different geographical locations and using different simulation tools and platforms they have also reported similar gains on VTL (about 35% reduction in commute time during rush hours) which endorsed our previous results which were conducted for the city of Pittsburgh. As mentioned in our previous Report in July 2013, the interest in Virtual Traffic Lights has increased exponentially in the last 1 year or so with feature articles in magazines like The Atlantic, new Scientist, Discovery Channel Canada, Gizmag, etc. AUDI, one of the top car manufacturers, have published a news item on VTL in its Encounter Technology Magazine in September 2013, showing as one of the groundbreaking developments in the automotive industry. 2-EXPERIMENTAL DATA MEASURED AT INTERSECTIONS: Some of the experimental data collected at intersections in Pittsburgh and the models used for modeling RF propagation between vehicles has been made available at the web site of T-SET UTC at Carnegie Mellon University to facilitate the use these models and data by other researchers as well. In addition, all the published papers and Technical Reports (before the corresponding papers were published) are posted on the UTC web site for quick dissemination of our findings. 3-VTL RELATED PROJECTS IN THE GRADUATE

Impact on the Development of the Principal Discipline: As mentioned before, several top-notch journal papers (as well as conference papers) have been published and/or submitted. In addition, several US patents have been filed through CMU as a result of this activity.

Impact on Other Disciplines: Our work is inter-disciplinary and has major impact on other disciplines such as engineering and public policy, civil and environmental engineering, application of biologically inspired paradigms to solve key transportation problems, building synergies between transportation, engineering, computer science, and natural sciences (such as biology and physics).

Smart Automotive Headlights for Driver Safety Lead: Srinivasa Narasimhan (CMU)


Smart Automotive Headlights for Driver Safety lead: Srinivasa Narasimhan (CMU)


Website: http://www.cs.cmu.edu/~ILIM/projects/IL/smartHeadlight/
Technologies and Techniques: Our technology for seeing through fog using a fusion of camera and radar has been shared with an Intel research group. Our smart headlight research is continuously being shared with Intel and Ford.

Other Products:

Inventions, Patent Applications, and/or Licenses:

Other Organizations Involved as Partners: 

Organization Name: Intel Corporation Location: Intel Science and Technology Center in Embedded Computing - Pittsburgh, USA. Financial Support: Approximately 100,000 in direct costs for 2013. Collaborative Research: Eriko Nurvitadhi and Mei Chen are Intel Employees collaborating with CMU researchers on this project.

Organization Name: Ford Motor Corporation Location: Detroit, USA Financial Support: Approximately 40,000 in gift as part of the FORD URP Award to the PI. Collaborative Research: Mahendra Dassanayake, Senior Technical Leader in the Headlight Division is collaborating with us on issues of implementing the prototype on Ford Vehicles.

Other Collaborators: University Collaborators: Prof. Anthony Rowe, ECE Department, Prof. Takeo Kanade, Robotics Institute.

Impact on the Development of the Principal Discipline: The project presents a revolutionary new design for vehicular exterior lighting as well as a new design for the broader optics and computational illumination and imaging communities. The prototype built in this project can be used potentially for many tasks to help drivers - reduce glare, highlight signs and obstacles. Developing and incorporating this prototype into commercial vehicles is a longer term goal that is certain to reduce crashes and increase driver safety.

Impact on Other Disciplines: The primary intent and potential impact of the project is to enhance driver, vehicle and traffic safety to reduce crashes.

Task List: We have built a prototype for a smart headlight with a fast light throughput (more than 1 kHz) and very short latency (1.5-2.5 milliseconds). Initial algorithms for anti-glare and snow conditions (generated via fake snow) have been developed and tested in simple road conditions with a stationary vehicle. The motion compensation and tracking methods developed will be incorporated into a moving vehicle in the year 2014. This will be followed by engineering effort to miniaturize the prototype to fit in most vehicles.

Goals and Associated Timeline for Deploying this Technology: Initial prototype for feasibility study was completed in 2012. In 2013, the prototype was re-engineered to be significantly faster so it can be deployed in highways. In 2014, the plan is to develop robust algorithms and test on a moving vehicle at regular speeds. In 2015, the plan is to miniaturize the prototype to fit within most vehicles. In 2016 and beyond, the technology will be transferred to a either a car manufacturer, a tier-1 car parts supplier or a decision to start a new venture will be taken. In initial discussions with a tier-1 supplier (Magna International), if the project succeeds, the approximate time to appear in commercial vehicles will be 5 years (2019-2020).

Attack Resilient State Estimation for Vehicular Systems Lead: Insup Lee (UPenn)

Publications: A conference paper is in preparation

Website: http://www.seas.upenn.edu/~nicbezzo/UTC.html Description: website containing information about the research on attack resilient state estimation for vehicular systems

http://precise.seas.upenn.edu/research/automotive/v2v/ Description: website containing information about the research on trust management applied on vehicular network

Technologies and Techniques: We have proposed an adaptive recursive estimator which uses a filter approach to estimate the state while reducing the malicious effects introduced by an attacker. Our recursive algorithm is motivated by the results found in the Kalman Filter implementation with some modifications to accommodate the possible presence of an attack in one of the sensors of a vehicle. If an attack is present and such that one of the measurements is corrupted, the goal is to remove it or mitigate its effect. Since the attack vector is generally unknown, the strategy we implement changes the covariance matrix associated with the measurement error in order to increase the uncertainty where the measurement is different from the predicted state estimate. The developed technique was applied to a cruise control case study on a wheeled ground robot.

Other Products: In collaboration with Prof. Daniel Lee and his group we developed a unmanned ground vehicle suitable to run experiments that involve sensors spoofing. The platform is equipped with a last generation computer which runs the Robot Operating System (ROS), and several sensors used to estimate specific states of the system.

Inventions, Patent Applications, and/or Licenses: We have developed a remote User Interface (UI) that allows to start and stop the robotic agent used during the experiments, run operations, and visualize and save data. The developed UI interacts with the ROS nodes on board the robot and produces a visual feedback for testing and debugging purposes.

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

Impact on the Development of the Principal Discipline: Improve the security and safety of modern vehicular systems. Support and train graduate students and postdoctoral researcher. Release software experiment platform to support further research.
Task List: Properly on-track with planned timing

Goals and Associated Timeline for Deploying this Technology: Goals: 1) Continue the research on novel technologies and techniques to improve the security and resilience against sensors, network, and actuators attacks on vehicular systems. 2) Expand the developed framework to more complicated case studies such as: adaptive cruise control, waypoint navigation in cluttered environments, and completely autonomous vehicles in urban environments. 3) Expand the developed techniques on multi-vehicle systems incorporating V2V and V2I protocols.

Pedestrian Collision Warning for SEPTA Lead: Daniel Lee (UPenn)

Publications: Student Presentation at Robotics Forum at Univ. of Pennsylvania, Jan. 2014.

Website: In preparation.

Technologies and Techniques: Innovative use of directed audio via nonlinear modulation of ultrasound for the warning system.

Other Organizations Involved as Partners: SouthEastern Pennsylvania Transit Authority

Impact on the Development of the Principal Discipline: This project is still in the basic research stage, but we are considering how to field a trial test in the coming year.

Impact on Other Disciplines: Will require innovative use of machine learning and signal processing techniques.

Task List: In development of initial prototype of warning system.

Goals and Associated Timeline for Deploying this Technology: Will result in large improvement over existing conventional speaker based warning systems.

Modeling Highway Accidents at the Micro-level Lead: John Landis (UPenn)

Technologies and Techniques: This project involved the first use of location-specific, micro-level accident data to develop a prototype statistical model of accident incidence and location based on congestion-levels, weather conditions, topography, and highway geometry. Pilot models were not found to fit the observed data particularly well, and we are currently investigating the use of other model structures and additional data to pursue this work.

Other Organizations Involved as Partners: Pennsylvania Department of Transportation

Task List: Investigating alternative model structures to more fully investigate project hypothesis.

Goals and Associated Timeline for Deploying this Technology: Completion June 2014.

Thrust Area #2 Smart Infrastructure

Bridge Monitoring Lead: Jacobo Bielak (CMU)

Publications: Conference Paper, peer reviewed Author(s): George Lederman, Zihao Wang, Siheng Chen, Fernando Cerda, Jacobo Bielak, James Garrett, Piervincenzo Rizzo and Jelena Kovacevic Title: Damage Quantification and Localization Algorithms for Indirect SHM of Bridges Conference: 7th International Conference on Bridge Maintenance, Safety and Management (IABMAS) Location: Shanghai, China Date: July 7-11, 2014 Status of publication: published, accepted, awaiting publication, submitted, under review, other: Accepted, to be delivered Acknowledgement of federal support (yes/no): Yes


Publication 4: Type of publication: Conference Paper Author(s): George Lederman, Zihao Wang, Jacobo Bielak, and Hae Young Noh Title: Data-Driven Inverse Problem Analysis for Indirect SHM Using Instrumented Vehicles Conference: Fourth International Symposium on Life-Cycle Civil Engineering (IALCCE) Location: Tokyo, Japan Date: November 16-19, 2014 Status of publication: abstract accepted, accepted, awaiting publication, submitted, under review, other: Abstract Accepted Acknowledgement of federal support (yes/no): Yes

Technologies and Techniques: We have a two pronged approach to SHM: collecting more realistic datasets, and developing new techniques to handle this data. Data Collection: In order to collect operational data from Pittsburgh Light Rail systems, we have designed an inexpensive data acquisition system using off-the-shelf components. In addition, we have built a database using a standard desktop computer and free database software. We believe these techniques could be used when implementing Indirect Structural Health Monitoring more widely. New Algorithms: We have made great progress over the last reporting period on a novel graph method. This technique has been submitted to IEEE's Transactions on Signal Processing, which is the premier signal processing journal.

Other Products: We have built a database which is growing with each new week of data. We plan to make this database publicly accessible on the internet as soon as we have published our results.

Other Organizations Involved as Partners: Partner Organizations 1 University of Pittsburgh, Pittsburgh PA. Through collaborator Piervincenzo Rizzo, a faculty member in the Civil and Environmental Engineering Department. (2) In kind support (4) Collaborative research Partner Organization 2 National Science Foundation, Arlington, VA. Through grant 1130616, "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. (1) Financial Support

Other Collaborators: Collaboration 1 We have continued working with the Port Authority (our main contacts are Bill Miller (COO) and Dave Kramer (Manager Railcar Maintenance)—we collect data continuously and download the data from the train on a weekly basis. This spring we will work with them to determine where repair work is going on so that we look for changes in our data. We will also begin our study of changes in the condition of the track. Collaboration 2 We continue to collaborate between Civil and Environmental Engineering (Faculty: Bielak, Garrett; Students: Cerda, Lederman, Wang) and Biomedical Engineering and Electrical and Computer Engineering (Faculty: Kovacevic; Student: Chen). Collaboration 3 We have collaborated with Christoph Mertz from the Robotics Institute. It was through Dr. Mert that we presented with Penn DOT in October and attended a bridge inspection this fall. In addition, we continue to use his state of the art robots. Collaboration 4 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.

Impact on the Development of the Principal Discipline: The impact of this program is two-fold. First this grant has allowed us to collect more realistic data and investigate new signal processing techniques to process this data. Second this grant has helped train civil engineering students to learn more about signal processing, while encouraging signal processing students, to examine applications in infrastructure. This past semester we have made significant progress collecting data from Pittsburgh's Light Rail Line. We have placed two uni-axial accelerometers inside a train car, and one triaxial accelerometer on the wheel truck. We have been continuously collecting data at high frequency to monitor the dynamic characteristic of the bridge and the track along the route. We have implemented a differential GPS system in order to tag the position of the data within 1 meter. We have configured our system to query national weather databases to determine the current and historical weather conditions at the point of interest. Lastly we have built a database so that all members of our research team can access the data in an efficient and secure manner. The large amounts of data require new analysis techniques. The goal is to be able to detect small changes. We have built an adaptive graph model that deals with the large number of variables and the high dimensionality of the data. In this technique, only a small number of the signals needs to be "labeled," i.e., for which the condition of the system is known. This frequently occurs in Structural Health Monitoring, because although data from the bridge might be collected every day, the condition of the bridge may only be checked once every two years when it is inspected. The adaptive graph model allows the condition from when the bridge is inspected to be propagated to the other data points (labeling the data to be healthy or unhealthy) according to the signal characteristics that are recorded. The manifold constructed in the graph model lies in a high dimensional space, which accounts for changing environmental factors, effectively normalizing for them. We continue to publish about this work in both the Civil Engineering Community (IABMAS conference, IALCE conference) as well as in the Signal Processing Community (ICASSP conference, IEEE Transaction on Signal Processing Journal). We hope that we might reliably detect "damage" (a change in the conditions, possibly due to repair or actual damage) in an operational system soon, which would be a huge milestone for indirect structural health monitoring. This research helps build a data-driven future for our transportation system by giving young engineers the advanced technical skills to lead the complex national infrastructure monitoring programs of the future.

Impact on Other Disciplines: This project lies at the intersection of Civil Engineering and Electrical and Computer Engineering, more specifically between Structural Health Monitoring and Signal Processing. One of the strengths of this project is that we draw on powerful tools outside of the typical realm of approaches for infrastructure monitoring. However, we have begun to move beyond simply applying existing technique to our datasets; we have begun to develop novel approaches that yield not only better results for our purposes, but better results in a wide range of applications. For example, the adaptive graph filter method has been used to classify political blogs according to where they lie of the ideological spectrum, and the results have been better than previous approaches. The impact on Signal Processing occurs through the publications in this field, as discussed earlier in the report.

Task List: All tasks have been completed
Goals and associated timeline for deploying this technology: We have deployed a test data acquisition system on the Pittsburgh Light Rail System. We plan to collect data for another 2 years both from bridges and from the track and to continue to test and develop new algorithms, as needed, in order to ultimately determine the robustness and generality of our approach. We expect to have a preliminary assessment within a year. At the end of two years we expect to be ready to deploy the system to other light rail or train systems. Depending on our progress, we may be ready to explore the applicability of our procedures in road vehicles.

Continuous Road Surface Distress Detection Lead: Christoph Mertz (CMU)


Website: Personal website: http://www.rni.cmuresearch.person.html?person_id=670
T-SET UTC Website: http://utc.ices.cmu.edu/utc/projectitem.asp?ID=57
T-SET UTC Website: http://utc.ices.cmu.edu/utc/Mertz%20project%20description.pdf
Open source data collection software for Android: https://bitbucket.org/lwander/snowcam

Technologies and 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.

Inventions, Patent Applications, and/or Licenses: An invention disclosure has been filed with CMU for the data collection system.

Other Products: We have a significant database of City of Pittsburgh road images. Summary analysis results are shared in publications. The database will be shared with the City of Pittsburgh.

Other Organizations Involved as Partners: City of Pittsburgh: Discussions about current practices of road asset management. Pilot test of our system. Cartegraph: Discussion about current practices of road asset management. In-kind support: Use and support of their asset management software.

Impact on the Development of the Principal Discipline: 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.

Task List: Develop smartphone based data collection app - done Develop software and scripts to automatically display the data on Google Earth or other geographical display tools - done Develop software that can automatically assess the road distress from the images - done Pilot test of system - ongoing Final report - not started

Goals and associated timeline for deploying this technology: The pilot test with the City of Pittsburgh is ongoing. We anticipate that by the end of 2014 they will make a decision if they want to make this system part of their operations. The data collection system is already part of a project with PennDOT. It is collecting data of snow plow operations. If this project is successful, the data collection system will become part of PennDOT operation. We anticipate this to happen in 2015. We are in talks with companies to further develop and employ these or related technologies. A rough estimate would be that commercial systems using our technologies would be available in 3 years.

Smart Parking Lead: Robert Hampshire (CMU)

journal Author(s): Hampshire, R.C., T. Fabusuiy and K. Sasanuma Title: Decision Analytics for Parking Availability in Downtown Pittsburgh Journal: Interfaces Volume: Year: Page numbers: Status of publication: accepted Acknowledgement of federal support (yes/no): yes

Other Organizations Involved as Partners: Organization Name: Numeritics LLC. Location of Organization: Pittsburgh, PA Partner's contribution to the project (identify one or more) Collaborative research (e.g., partner's staff work with project staff on the project); and Personnel exchanges
Impact on the Development of the Principal Discipline: Our results show the performance based pricing of on-street parking in San Francisco has been successful. Our major findings are (1) that SFpark is slowly achieving its goal of moving occupancy into a target range of 60-80%, and (2) SFpark has reduced cruising for parking by about 50%.

Our results show that real time parking information in Pittsburgh has reduced the time to find a parking space for 48% of those surveyed.

Goals and Associated Timeline for Deploying this Technology: Feasibility of a deployment are subject to further results from our simulations.
recognition system. (2) FLIR/Traffic - Traffic has provided CMU with video processing boards to support the initial SURTRAC deployment, and has continued to provide support in interfacing with their video detection hardware. (3) Econolite - Econolite has provided technical support in using their video cameras at some intersections in the expanded deployment.

Other Collaborators: The real-time bus recognition system has been developed by Aravindh Mahendran, an MS student in the Robotics Institute, in collaboration with Stephen Smith, Research Professor of Robotics (UTC project PI) and Martial Hebert, Professor of Robotics. Dr. Smith heads the parent SURTRAC adaptive traffic signal control project. Dr. Hebert is a world class vision researcher, who has extensive experience in vision and SVM-based object recognition. Other collaborators have included Gregory Barlow (Project Scientist, Robotics), who has provided support in conducting initial field tests of the bus recognizer, and Xiao-Feng Xie (Project Scientist, Robotics), who has developed the extensions to SURTRAC for exploiting bus detected events.

Impact on the Development of the Principal Discipline: It is common current opinion that real-time adaptive control systems are not effective in urban (grid) environments. Our research, and the results we have obtained with the initial and expanded SURTRAC adaptive system deployment, is disproving this impression and demonstrating instead that adaptive signal systems can enable significant improvement in traffic flow efficiency and air quality control in this context. Specifically, an innovative formulation of the intersection control problem allows timing plans for a given intersection to be generated as frequently as once a second, which enables a scalable, decentralized approach to coordinated network level signal control. The approach does not rely on a priori knowledge of the dominant traffic flows, and can thus dynamically accommodate multiple, conflicting flows that evolve over time. With the integration of detection capabilities for buses, pedestrians and other traffic modes, the goal is to promote safe, multi-model traffic flow optimization. Congestion costs in US urban areas (in terms of time lost and fuel consumption) are estimated to be $101 Billion (2011 Annual Mobility Report). Scalable adaptive signal control techniques such as those we are developing can have a profound impact. The real-time bus recognition project combines research in real-time distributed planning/scheduling, and computer vision, and is advancing knowledge at the intersection of these two disciplines.

Task List: We have achieved our overall 2013 project goals and completed our task list. In 2014, we will take continued steps toward deployment of the developed bus recognizer and also expand focus to include pedestrian detection.

Thrust Area #3: Human-Vehicle Interactions for Safe Driving

Modeling, Verification, and Transportation Safety Lead: Andre Platzer (CMU)


Website: http://www.cs.cmu.edu/~smitsch/

Technologies and Techniques: As a case study in formal verification of transportation systems, we analyzed the efficiency of an adaptive cruise control system, in which control decisions are made based on position and velocity information received from other vehicles via V2V wireless communication. If the vehicles follow each other at a close distance, they have better wireless reception but collisions may occur when a follower car does not receive notice about deceleration of the leader car fast enough to react before it is too late. If the vehicles are farther apart, they would have a bigger safety margin, but the wireless communication drops out more often, so that the follower car no longer receives what the leader car is doing. In order to guarantee safety, such a system must return control to the driver if it does not receive an update from a nearby vehicle within some timeout period. The value of this timeout parameter encodes a tradeoff between the likelihood that an update is received and the maximum safe acceleration. We combined formal verification techniques for hybrid systems with a wireless communication model, and analyzed how the expected efficiency of a provably safe adaptive cruise control system is affected by the value of this timeout.

Other Products: Simulation of hybrid programs The dL simulation toolkit translates hybrid programs into executable Mathematica instructions. The simulation environment is integrated into KeYmaera and into the hybrid program modeling toolkit Sphinx. It enables users of these tools to gain an intuition about the modeled system behavior. The software can be downloaded freely as part of our theorem prover KeYmaera (http://symbolaris.com/info/KeYmaera.html).

Other Organizations Involved as Partners: Johannes Kepler University, Linz, Austria Collaborative research: we hosted visiting researcher Andreas Mueller from Johannes Kepler University, Linz
Vehicle Detection and Counting at Road Intersection Using Video Data

Lead: Camillo Taylor (UPenn)

Publications: Author(s): Title: Journal: Volume: Year: Page numbers: Status of publication (published, accepted, awaiting publication, submitted, under review, other): Acknowledgement of federal support (yes/no):

Impact on the Development of the Principal Discipline: Collaboration with Johannes Kepler University, Linz, Austria: collaborative research (hosted visiting researcher Andreas Mueller) Undergraduate course at Carnegie Mellon University: Foundations of Cyber-Physical Systems (Fa'13), Computer Science Department (15-424/15-624), Carnegie Mellon University, Fall 2013. The students developed increasingly complex models of autonomously driving ground vehicles, which had to avoid obstacles.

Impact on 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 situation awareness software framework for traffic control centers. We hosted Andreas Mueller, a visiting researcher from Johannes Kepler University, who worked on building blocks for composing hybrid models of traffic systems from basic traffic components (e.g., traffic lights, lanes).

Task List: Year 1 We formally studied intelligent speed adaptation and incident management systems for freeway traffic control. We studied how cyber-physical system technology can help improve freeway traffic by combining local car GPS positioning, traffic center control decisions, and communication to achieve more tightly coupled feedback control in intelligent speed adaptation. We developed models for an intelligent speed adaptation that respects variable speed limit control and incident management. We identified safe ranges for crucial design parameters in these systems and, using the theorem prover KeYmaera, formally verified safety of the resulting cyber-physical system models. Finally, we showed how those parameter ranges could be used to decide trade-offs for practical system implementations even for design parameters that are not modeled formally. We presented a new approach for leveraging the power of theorem provers for formal verification to provide sufficient conditions that can be checked on embedded control designs. Theorem provers are often most efficient when using generic models that abstract away many of the controller details, but with these abstract models very general conditions can be verified under which desirable properties such as safety can be guaranteed for the closed-loop system. We propose an approach in which these sufficient conditions are static conditions that can be checked for the specific controller design, without having to include the dynamics of the plant. We demonstrate this approach using the KeYmaera theorem prover for differential dynamic logic for two examples: an intelligent cruise controller and a cooperative intersection collision avoidance system (CICAS) for left-turn assist. In each case, safety of the closed-loop system proved using KeYmaera provides static sufficient conditions that are checked for the controller design.

Year 2 We studied general operating conditions, including inaccurate sensing, actuator disturbance, and sensor failure with an obstacle avoidance system for autonomous robotic ground vehicles. We modeled the behavior of autonomous vehicles that are equipped with the Dynamic Window Approach for obstacle and collision avoidance and formally studied several safety properties in the presence of stationary and moving obstacles. We verified safety using the theorem prover KeYmaera. Furthermore, we formally verified safety of the algorithm even in presence of bounded sensor inaccuracy (i.e., inaccurate position measurement, such as GPS), actuator disturbance (i.e., braking and acceleration may be damped), and partial failure of the position sensors (e.g., GPS fails, but wheel encoders still allow dead reckoning). We analyzed the efficiency of an adaptive cruise control system (which we already proved to be safe previously) when being implemented with V2V wireless communication. The V2V wireless communication introduces communication delays and message loss. If the vehicles follow each other at a close distance, they have better wireless reception but collisions may occur when a follower car does not receive notice about deceleration of the leader car fast enough to react before it is too late. If the vehicles are farther apart, they would have a bigger safety margin, but the wireless communication drops out more often, so that the follower car no longer receives what the leader car is doing. We combined formal verification techniques for hybrid systems with a wireless communication model, and analyzed how the expected efficiency of a provably safe adaptive cruise control system is affected by the value of this timeout. We developed "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 robots as a running example throughout the course. This course was held in the fall term 2013.
**Technologies and Techniques:** Traffic analysis studies are commonly performed to inform policy makers about the rate of traffic flow and the prevailing traffic patterns at key intersections. In urban environments, like Philadelphia, one common approach to conducting these studies is by temporarily deploying a video camera that acquires footage over a period of study. This video is then analyzed to produce data on the routes that cars take at the intersection over that time period. Once the video data has been obtained it can be manually annotated to obtain the required traffic count or turn information. As one can imagine, this is a time and labor intensive process. Alternatively, there are a number of commercial entities such as Miovision that have automated or semi-automated systems that can perform this function. Planning agencies can contract with these services for a fee to perform these counts. What we are seeking to do in this project is to develop open source video analysis software that would reduce the cost of acquiring this data and, thus, make it possible to acquire more information about traffic flow in a timely manner. Ultimately we would like to develop algorithms that could be deployed on small, inexpensive embedded smart camera systems which could provide real time information about hundreds of intersections and give traffic planners and city operators an unprecedented level of information about traffic conditions.

**Other Organizations Involved as Partners:** Delaware Valley Regional Planning Commission (DVRPC)

**Impact on the Development of the Principal Discipline:** Through this project we have been able to expose a number of masters and undergraduate students to the challenges of automated traffic analysis. The student participants in this project are listed below: Takashi Furuya Beau Kuhn Miraj Shah Amey Pendharkar

**Impact on Other Disciplines:** Our hope is to develop technological solutions that will allow us to collect data that will impact the discipline of transportation planning.

**Task List:** Most of our effort this year has been spent on fundamental video analysis. We have acquired actual video footage from our partners - the DVRPC. We have implemented several image based tracking algorithms both in Matlab and in OpenCV. We have demonstrated the real-time tracking performance using a simple background model and we are currently experimenting with more sophisticated feature based tracking schemes.

**Goals and Associated Timeline for Deploying this Technology:** We are currently running experiments with our techniques on video footage that we have collected and are hoping to improve the accuracy of the current video analysis methods. Progress has been steady but we have not achieved the level of count accuracy that we want so our goal is to improve count accuracy above 90%. We are also exploring another approach to vehicle detection that would use infrared imagery which would provide greater contrast and better resilience to changing weather conditions. We are investigating the option of acquiring a specialized smart camera system which would include some built in tracking capabilities. If this is successful it would speed deployment and experimentation and allow us to conduct outdoor tests within the year.

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**Thrust Area #4: Large-Scale Mobility and Data Analytics**

**Distributed Transit Rider Messaging Lead:** Aaron Steinfeld (CMU)

**Website:** http://www.tiramisutransit.com


**Technologies and Techniques:** The team has further developed SmartWrap, an extension of our existing Mixer system that focuses on the extraction of tables from the web. Current activities include utilizing Amazon Mechanical Turk to evaluate the system. Turker experiments are validating the interface, helping us understand the capabilities and limitations of end users as constructors of wrappers for transit sites (and other tabular sites).

**Other Products:** The team has also deployed a working version of SmartWrap to the public as a Firefox add-on. The software has been downloaded over 100 times since late November.

**Other Organizations Involved as Partners:** The team has continued to share progress and plan collaboration with colleagues at IBM Research, with whom some early discussions regarding Mixer occurred. Representatives of IBM Research Japan visited December 11-12, 2013.

**Other Collaborators:** The team has continued discussions with colleagues at Booz Allen Hamilton.

**Impact on the Development of the Principal Discipline:** Our current work on SmartWrap is advancing the science on how to enable non-programmers to acquire and manipulate information from websites. This has significant potential impact on interactions with legacy systems and utilization of information on third party websites without the high cost of custom programmed web scrapers.

**Impact on Other Disciplines:** While still being deployed to other disciplines through the Firefox add-on and impact is too early to measure, SmartWrap has utility beyond transportation. It has drawn the attention of colleagues in medical records and other white-collar domains.
The SmartWrap/Mixer concept provided the basis for a project within the recently awarded RERC on Physical Access and Transportation (Dept Ed, H133E130004). This project will utilize concepts and code from this effort to allow people with disabilities, their caregivers, and clinicians to generate and update personalized information tables built from information scraped from the web.

Goals and Associated Timeline for Deploying this Technology: We hope to be deploying the Tiramisu message version with alerts from Port Authority of Allegheny County sometime in the first half of 2014. The results for our human participant study on the web collection tool for non-programmers will be revised for publication submission. We are preparing additional publications on field experiments.

Enhancing the Safety of the Carnegie Mellon Campus for Blind Pedestrian Lead: M. Bernardine Dias (CMU)


Book Author(s): M. Beatrice Dias, Ermine A. Teves, George J. Zimmerman, M. Bernardine Dias Title: Indoor Navigation Challenges for Visually Impaired People Book: Indoor Wayfinding and Navigation Volume: N/A Year: N/A Page numbers: N/A Status of publication (published, accepted, awaiting publication, submitted, under review, other): Other – Abstract Approved and Invited Submission Acknowledgement of federal support (yes/no): Yes

Book Author(s): M. Bernardine Dias, M. Beatrice Dias, Satish Ravishankar, Aaron Steinfeld Title: State-of-the-art In Navigation Aids for Visually Impaired People Book: Indoor Wayfinding and Navigation Volume: N/A Year: N/A Page numbers: N/A Status of publication (published, accepted, awaiting publication, submitted, under review, other): Other – Abstract Approved and Invited Submission Acknowledgement of federal support (yes/no): Yes

Book Author(s): M. Bernardine Dias, M. Beatrice Dias, Satish Ravishankar, Ermine A. Teves Title: The NavPal Suite of Tools for Enhancing Blind Indoor Navigation Book: Indoor Wayfinding and Navigation Volume: N/A Year: N/A Page numbers: N/A Status of publication (published, accepted, awaiting publication, submitted, under review, other): Other – Abstract Approved and Invited Submission Acknowledgement of federal support (yes/no): Yes

Book Author(s): M. Bernardine Dias, M. Beatrice Dias, Aaron Steinfeld Title: Future Direction of Work in Assistive Navigation Technology Book: Indoor Wayfinding and Navigation Volume: N/A Year: N/A Page numbers: N/A Status of publication (published, accepted, awaiting publication, submitted, under review, other): Other – Abstract Approved and Invited Submission Acknowledgement of federal support (yes/no): Yes

Website: http://www.cs.cmu.edu/~navpal Main project website where this work is described as a part of the broader NavPal research project and where further details about specific activities related to "Enhancing the Safety of the Carnegie Mellon Campus for Blind Navigators" will be featured. Website was modified during the 6-month period to capture work to date on the NavPal project.

Technologies and Techniques: As previously reported, work to date on the NavPal project has resulted in three primary technology tools: (1) a smartphone app to give navigational assistance to blind adults as they move around unfamiliar indoor environments, (2) an accessible online tool that allows blind adults to pre-plan routes in an unfamiliar indoor environment, and (3) online software tool for creating and editing building maps such that they can be easily made accessible to blind travelers. All of these tools have been enhanced in this report period, continue to be shared with a variety of audiences through informal presentations, and continue to involve both undergraduate and graduate students in the needs assessment, design, implementation, and user testing of these tools.

Other Products: We have collected new needs assessment data to further support this project through our connections with local partner organizations and potential end users of the tools. We are working on book chapters and other means of sharing this information. We also describe this data in our presentations. Our research team is handling the data and disseminating the results in accordance with CMU IRB regulations for research involving human subjects (CMU IRB Protocol # HS13-349).

Other Organizations Involved as Partners: Organization Name: Western Pennsylvania School for Blind Children (WPSBC), Blind and Vision Rehabilitation Services of Pittsburgh (BVRS).

Other Collaborators: Faculty from the University of Pittsburgh continue to communicate with our team on potential compatibility of our research projects on navigation and wayfinding for people with visual or ambulatory challenges.

Impact on the Development of the Principal Discipline: In terms of impact in the field of computing technology, this work continues to advance the state of the art in assistive technology for the visually impaired, and also informs future researchers in this area about the requirements, needs, challenges and opportunities for computing technology to have positive impact on the lives of visually impaired people. This work also continues to have relevance in the areas of smart cities, navigation technologies, and user interface design. Due to the many students we have involved in our work, we are also training a new generation of researchers and developers.
who are attuned to the needs of the visually impaired community, and are meaningfully able to develop technology of impact in this underserved community. When they start working with our group, most of these students have never thought about how most technology can be inaccessible to visually impaired people. However, once their work with our group is complete, the students are usually passionate about ensuring more technology is useful and accessible to the visually impaired community. Our community partners continue to inform our work in important ways and also benefit from our work through increased guided exposure to technology and access to the technology tools we develop. The findings from this work also informed two new successful grant proposals from the National Science Foundation and the National Institute on Disability and Rehabilitation Research (NIDRR). Both of these grants will contribute to furthering the work started on this project, as well as extending this work in new directions such as the exploration of assistive robots for blind travelers.

Impact on Other Disciplines: We have seen a surge of interest in our work during this report period from non-technical communities. Specifically, we see growing interest from Orientation and Mobility specialists, leaders of support organizations for visually impaired people, building managers, and visually impaired adults. Our work also continues to impact the overall dialog and relevant policies on accessibility in the digital age.

Task List: We have now completed our work on this project grant.

Goals and Associated Timeline for Deploying this Technology: Our goal for the future is to continue to enhance these tools and eventually deploy them at a larger scale either commercially or via open source avenues.

AutoMatrix: A large-scale traffic congestion modeling tool to investigate anytime algorithms for multi-core computing architectures
Lead: Rahul Mangharam (UPenn)

Website: http://mlab.seas.upenn.edu/research/real-time-parallel-computing/automatrix/

Technologies and Techniques: Anytime Algorithms for Autonomous Vehicles: In semi-autonomous vehicles, algorithms for trajectory control, obstacle avoidance and path planning/navigation are very compute-intensive and require a lot of processing. These algorithms must run in an on-line and real-time manner within the closed-loop context of the moving vehicle. Currently, the computer vision processing bottleneck for sensor data capture (by cameras, position sensors and laser range finders) is the bottleneck and restricts fast vehicle responsiveness and faster velocities. This project if focused on the development of approximate and imprecise computation algorithms that take the large amount of data generated by these sensors and provide the best possible answer within the deadline, so the vehicle is always safe and responsive. We are developing this architecture to run on graphics processors (GPUs) and will demonstrate the safety and efficacy on both modeled vehicles and full-scale vehicles. This project has large impact in making low-cost sensing more viable by ensuring the processing is more effective and appropriate for the situation the vehicle is in.

Other Products: AutoMatrix is free and open source software

Other Organizations Involved as Partners: Paul Gurniak, Ph.D. candidate at University of Pennsylvania

Other Collaborators: Yash Pant, Ph.D. candidate at University of Pennsylvania; Truong Nghiem, Post Doctoral Fellow at University of Pennsylvania

Impact on the Development of the Principal Discipline: Collaboration with Dan Lee and his team on the development of low-cost control and computation algorithms for vision-guided autonomous vehicles. We are developing algorithms to replace high cost LiDAR and RADAR navigation systems with cheap off-the-shelf CMOS cameras for autonomous vehicle functions. The algorithms developed in this project perform feature extraction on the camera images, classify objects (vehicles, pedestrians, infrastructure) and produce motion estimates to provide an input @30ms to the Trajectory Controller, @300ms to the Obstacle Avoidance Controller and @3s to the Path Planning Controller.

Impact on Other Disciplines: This is an early effort to 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.

Task List: We have developed the overall framework for the estimation computation algorithms and control algorithms in simulation. We are now developing a demonstration test-bed to showcase the capabilities of this system. The step after that is to incorporate visual odometry data to show how the new approach is as efficient as bulkier and more expensive technology.

Goals and Associated Timeline for Deploying this Technology: We are implementing this research.
ProtoDrive: An Experimental Platform for Electric Vehicle Energy Scheduling and Control

Lead: Rahul Mangharam (UPenn)

Publications:

Website: http://mlab.seas.upenn.edu/protodrive/

Technologies and Techniques:
We have developed Protodrive, an experimental platform enabling rapid prototyping and simulation of electric vehicle powertrains. The powertrain is modeled at the small-scale in hardware, making it low-cost and compact enough to fit on a desk. It consists of a physical model of an electric vehicle powertrain coupled to an active dynamometer, making it possible to run the powertrain through its full speed and torque range. The fact that this system has been constructed in hardware allows it to capture intricacies in vehicle operation that may be missed by simulation in software alone. To investigate battery-supercapacitor charge/discharge control and scheduling strategies for range maximization, peak current draw minimization and maintaining the battery temperature in the efficient operating region we begin with an energy-efficient hybrid system that comprises of both, the batteries and the supercapacitors connected through a DC/DC converter to achieve optimal performance. The inputs to the system are the EPA’s Federal Drive Cycle and real vehicle model information from the EPA, the U.S. Department of Energy (DoE) and the National Renewable Energy Laboratory (NREL). Various power distribution schedules will be implemented over the drive cycle, enabling the comparison of a hybrid system to a battery-only system, and the comparison of various current distribution algorithms. The output will show the current load on the battery and the super capacitor, which can be used to determine the battery’s State of Charge and the efficiency of the vehicle. Ultimately, we aim to determine if a battery/supercapacitor system offers significant benefits over a battery-only system, by simulating real commuting routes in hardware.

Other Products: Protodrive is free and open source - http://mlab.seas.upenn.edu/protodrive/ Watch the video - https://www.youtube.com/watch?v=ZWhTuTwJ4npk

Other Organizations Involved as Partners:
- Harsh Jain, MS, Embedded Systems, UPenn
- Abhijeet Mulay, MS, Embedded Systems, UPenn
- Yash Pant, PhD Candidate, Electrical Engineering, UPenn
- William Price, BS, Electrical Engineering, UPenn
- Stephanie Diaz, BS, Electrical Engineering, SUNY Binghamton
- Alex Styler, PhD Candidate, CMU

Impact on the Development of the Principal Discipline: Protodrive can be used for a wide range of simulation tasks, and presently the benefits of a battery-supercapacitor powertrain are being investigated. Protodrive runs a scaled version of an actual commute drive cycle with various battery/super capacitor charging/discharging schedules with the goal of maximizing the battery’s life time and the vehicle’s range. Protodrive has a number of interesting applications that will further EV development: - Enabling rapid prototyping and evaluation of novel powertrain architectures - Simulating federal drive cycles to determine a vehicle’s fuel consumption and MPGe rating (Miles Per Gallon equivalent) - Predicting range, when coupled with elevation data from Google maps and a driver control strategy


Task List: We have completed the development of the electric vehicle testbed. The platform runs the ProtoDrive peak-power control and scheduling algorithms for battery-supercapacitor hybrid energy storage systems.

Goals and Associated Timeline for Deploying this Technology: We have completed the development of the electric vehicle testbed. The platform runs the ProtoDrive peak-power control and scheduling algorithms for battery-supercapacitor hybrid energy storage systems. Our goal is to develop a community web portal for automatic drive cycle updates and route guidance services for electric vehicles.

Visual Navigation using Embedded Tablets

Lead: Daniel Lee (UPenn)

Publications: Presentation at Intel Embedded Systems Science and Technology Center, August 2013
Website: Not available due to NDA.

Technologies and Techniques: Visual odometry based navigational aids for automotive embedded computing platforms.

Inventions, Patent Applications, and/or Licenses:

Other Organizations Involved as Partners: Intel Research. Also have been in negotiations with Honda Research to develop test prototype.

Impact on the Development of the Principal Discipline: Would provide a very inexpensive driver navigation aid based upon existing tablet devices.

Impact on Other Disciplines: Application of computer vision and machine learning.

Task List: Currently implementing code for initial prototype.

Goals and Associated Timeline for Deploying this Technology: Would ultimately like to partner with automotive company to test prototype.

Visualization and Analysis of Railway Safety Incidents Lead: Camillo Taylor (UPenn)

Technologies and Techniques: The Southeastern Pennsylvania Transportation Authority (SEPTA) is one of the largest metropolitan transit systems in the world, with an annual ridership of nearly 340 million [12]. A major concern with such a large transportation system is safety: each year, many safety incidents occur on SEPTA transit systems, particularly the Regional Rail Lines. Our work discusses the proposed implementation of a Geographic Information System (GIS) to be used by SEPTA. GIS help to transform collected geographic data into useful information.

Other Organizations Involved as Partners: South Eastern Pennsylvania Transit Authority

Other Collaborators: Student team members (UPenn undergraduate students) Scott Biddle Arda Kuyumcu Amanda Pacheco Gorkem Yurtseven

Impact on the Development of the Principal Discipline: SEPTA is the sixth-largest commuter rail system in the country [12]. As with any large public transportation system, safety is a very high priority, particularly on regional rail. Regional rail combines the high-speed danger of subways systems, with the easy, above-ground access of bus and light rail systems into a dangerous safety risk. Regional rail trains can travel up to 90 miles per hour, and are so massive that it can take them over a mile to come to a complete stop. Sadly, once a train engineer sees someone on the tracks, there is hardly anything they can do to stop it which has caused many engineers to quit their jobs due to post-traumatic stress. This report starts by giving background information on SEPTA’s regional rail and geographic information systems (GIS). It then discusses related work in the field of GIS and moves forward to analyze the web application. An analysis of our web application is provided in terms of this model, the implementation techniques our group has been using, and its performance. The paper concludes with the results of the application, a conclusion of the paper and ethical challenges the web application faced.

Task List: Project was completed in May 2013

Thrust Area #5: Policy & Guidance

Assessment of Communication and Information Technologies in Transportation Lead: Chris Hendrickson (CMU)


Other Organizations Involved as Partners: PADOT, Cranberry Public Works

Impact on the Development of the Principal Discipline: Highlighted importance of signal timing updating.

Impact on Other Disciplines: Traffic signals of interest to civil engineers, urban planners and public works managers.

Task List: Complete.