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Tier 1 University Transportation Center

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Signature: [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 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.
  - Number of conferences, meetings, and formal discussions that focus on and 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

Our major education accomplishment this period is the hiring of Sean Qian, Assistant Research Professor, specializing in transportation. He is a joint appointment between the Heinz College and the College of Engineering at CMU. He will work closely with the UTC to forward our research while teaching courses in transportation.

In workforce development, on April 18th, Dr. Raj Rajkumar gave a presentation of the autonomous vehicle research underway as part of the GM-CMU Cooperative Lab at a meeting of the Pennsylvania Chapter of ITS America. Dr. Rajkumar also showed the attendees the actual research vehicle and all of its technical features following his presentation.

During the spring semester at the Heinz College (CMU), a graduate level Systems Synthesis course allowed students to develop projects with a real-world partner, the Port Authority of Allegheny County. The goal of the project was to uncover transit inefficiencies within Port Authority. The UTC is now seeking to create a Fellowship in order to continue working with the students to expand the project beyond the scope of the class.

In education, Carnegie Mellon has developed an ITS course for the Governor's School for Science, a five-week summer program for gifted high school students in the state of Pennsylvania. Admission into the program is very competitive - approximately 500 of the most scientifically gifted students in the state compete for the 100 spaces in the program.

Various T-SET personnel at CMU have been actively engaged in a campus wide effort to consider the development of an urban systems data institute, which would include intelligent transportation systems.

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

- RITA/CUTC Student of the Year Banquet in Washington DC, CMU PhD student Yeganah Mashayekh received one of the CUTC Student Awards, which were presented by Acting Administrator Gregory Winfree.
- Interview Faculty Candidates for New ITS Faculty Position
- Present T-SET Research to Students at a Heinz College Colloquium
- National Engineers Week Demo at the Carnegie Science Center (targeting 6-17 year-olds)
- Advise Heinz College Graduate Systems Syntheses Course Group Presentation on Increasing Transit Efficiencies
- Attend Event for Pittsburgh Chapter of the Young Professionals in Transportation
- Planning the Urban Systems Institute aka Connected Communities Institute
- On committee hosted by Suh Foundation, to explore how data bases can be shared including in transportation sector

Technology Transfer and Collaboration

Carnegie Mellon has successfully executed a five-year master agreement with the Pennsylvania Department of Transportation (PennDOT) and developing work plans of T-SET research projects that address real world transportation challenges of PennDOT and utilize Pennsylvania as a test bed for ITS deployment.

On May 15, T-SET hosted its first Technology Transfer Symposium at CMU. We worked with CMU's Center for Innovation and Entrepreneurship. Five UTC research projects were presented to an audience of investors, foundations, and other entrepreneurship and tech transfer professionals. Faculty then got to learn about how to transfer their own technology through presentations by the Center for Technology Transfer and Enterprise Creation, AlphaLab, and Innovation Works. After the presentations, there was an entrepreneurial mixer where Entrepreneurs-in-Residence talked to UTC faculty one-on-one.

Below are additional Technology Transfer and Collaboration accomplishments and efforts:

Hosted the following:
- PennDOT CMU Tour and Autonomous Vehicle Demonstration
- Transportation Research Board Annual Meeting
- ITS America Open House
- Bus Rapid Transit Workshop
- Greater Pittsburgh Chamber of Commerce Event with PennDOT

Attended the following:
- RITA UTC Winter Meeting in Washington DC
- PennDOT State Transportation Innovation Council Meeting in Harrisburg
- Innovation Works Annual Meeting and Technology Demo
- Chamber of Commerce Event with Congressman Mike Doyle
- Meeting of the Southwestern PA Commission Public Participation Panel
- Southwestern PA Commission Freight Conference
- Joint Pittsburgh and Philadelphia Chambers of Commerce Legislative Reception in Harrisburg
- Leadership Meeting of Pittsburgh Chapter of the Association of Unmanned Vehicle Systems International
- New Cities Summit in Sao Paulo Brazil
- Greater Pittsburgh Chamber of Commerce Investors Summit
- CUTC - UTC Summer Meeting in Memphis
- Tour of Bus Rapid Transit System in Cleveland
- Transportation Camp in Washington DC

Held meetings with the following:
- Rockefeller Foundation on Pittsburgh BRT Project
- Hillman Foundation for Tiramisu Marketing
- Remaking Cities Institute
- 10,000 Friends of PA
- Pittsburgh City Planning and RIDC
- PennDOT Traffic Management Center
- Quality of Life Technology Center
- Garnett Fleming
- Pennoni Associates
- CMU Project Olympus Program and Don Jones Center for Entrepreneurship to discuss technology transfer educational events for faculty and students
- Pittsburgh City Planning and Adaptive Signal Team

- Pittsburgh Public Schools for "Where's My School Bus?" App
- Southwestern PA Commission and Researchers to Discuss Applications for Traffic Incident Management
- Cartograph Meeting to Discuss Bridge Monitoring
- Port of Pittsburgh Commission to Discuss Applications for the Wireless Waterway
- Pittsburgh Airport Authority to Discuss UTC Research Pilots at the Airport
- Agriculture Robotics Firm to Discuss Autonomous Vehicle Research
- Airport Authority to Discuss T-SET Consortium
- University of Pittsburgh to Discuss the Almono Project
- Heinz Endowments to Discuss the Route 51 Project
- University of Pittsburgh to Discuss Data Center
- Pittsburgh Parking Authority to Introduce a Finalist from Steel City Codefest with a Smart Parking App
- IBM to Discuss the Pittsburgh Smarter Cities Challenge Follow-up
- ITS America to Discuss CMU Remaking Cities Institute Research
- Denver Metro Leadership Foundation to Advance Benchmarking Trip to Pittsburgh with a T-SET Presentation
- Pittsburgh Parks Conservancy to Discuss the Schenley Drive Roundabout
- Pennsylvania Environmental Council to discuss trail mapping
- PennDOT to discuss research projects

Joined the following:
- Pennsylvania Chamber of Commerce Transportation Committee Meeting

Diversity

Discussions continue regarding the collaboration with the Community College of Allegheny County, which with a 24% enrollment of ethnic minorities can be an opportunity for diversity outreach.

The UTC continues to work with Indiana University of Pennsylvania and the Indiana County Transit Authority to transfer UTC technology to serve rural populations in Pennsylvania.

Additional Diversity Outreach Activity

- Ailis McPhail presented at annual COMTO meeting in Florida.
- Working with CMU’s ICES to be part of SEE program for high school girls.

Dissipation of Results

In June, Raj Rajkumar presented at Rutgers University for the University Transportation Research Center's Second Annual Connected and Self-driven Vehicles Symposium. The symposium brought industry, government and academia together to explore the future directions in research and deployment of connected vehicle technologies. Raj was selected to be part of a representative sample of academic research initiatives and what universities are doing in terms of developing and integrating test-beds for connected vehicle research.

In addition to the outreach activities mentioned above and UTC researcher activity in Appendix A, UTC leadership personnel attended the following conferences and meetings to promote UTC research, technology transfer, education and workforce activities:

- Present T-SET to Innovation Oakland
• Testimony at the request of the Pa House Democratic Policy Committee on intelligent transportation systems.
• Briefing of Ellen McLean, Acting CEO of the Port Authority of Allegheny County.
• IBM discussions with Wayne Salta et al.
• State Transportation Innovation Council.
• Senior staff of Auditor General conference call, providing background on Turnpike and transportation funding.
• Pittsburgh City Planning Director Noor Ismail and team briefed on transit alternatives.
• Raj Rajkumar presented at the T-SET Faculty Seminar on Autonomous Vehicles which is available online: http://www.youtube.com/watch?v=Nu8PKmKmEzc
• Present Traffic Incident 3-D Visualization Research to Airport Area Traffic Incident Management Team
• Keynote Presentation on Autonomous Vehicle Research and Vehicle Demo to Mid Atlantic Section of the Institute of Transportation Engineers.
• Interview with ITS America for Their Connected Vehicle Report.
• T-SET Presentation to State Senator Matt Smith.
• Demo both CMU and Penn UTC Research at the ITS America Capitol Hill Transportation Technology Showcase in Washington, DC.
• Steven Smith presented at the T-SET Faculty Seminar on Adaptive Traffic Signals, the event was also streamed live and had over 100 audience members from the web.
• T-SET Presentation to Researchers from Toshiba
• Presentation of T-SET to PA Auditor General Gene DePasquale
• Presentation to the Power of 32 Implementation Committee on Traveler Information Report.
• Interview with Duke University Researchers to Discuss Traffic 21 Model.
• Presented Adaptive Traffic Signals at the Google Pittsburgh Office.
• 2013 Global Symposium on Connected Vehicles and Infrastructure.
• US DOT Transportation Data Palooza.
• AUVI’s Driverless Car Summit.
• ITS America Annual Meeting.
• Workshop on the Future of Road Vehicle Automation.
• **Integrate with CMU’s Palo Alto campus, T-SET/T21 roadshow/Meet with PATH at Berkeley.

Plans for Next Reporting Period

• Continue deployment progress on the research projects.
• Hold Advisory Council Meeting.
• Continue strategically planning for expansion of the UTC.
• Continue individual follow-up with advisory members on “what we want to be when we grow up.”
• Hold a targeted technology transfer symposium for UTC faculty and students involving campus affiliates and consortium members who provide technology transfer assistance.
• Further develop STEM and diversity initiatives.
• Continue media exposure of upcoming noteworthy research activity.
• Push research publications to TRB for coverage in their weekly newsletter.
• Explore creating videos on UTC projects for increased engagement on the internet.

2. Products

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

General Program Products

• Hired T-SET UTC project manager.
• UTC website www.utc.ices.cmu.edu.
• Began to rollout PODIO, an cloud based database for research projects.
• 438 blog postings since January 2013.
• Consistent weekly distribution of T-SET email newsletter, 747 subscribers.
• New presence on social media, 15 fans on Facebook and 67 followers on Twitter.
• Continue to use a webinar-based system of linking CMU and UPenn faculty and students for our bi-weekly T-SET meetings. Now a faculty member interactively presents their research at the beginning of each meeting.
• Promotion of various CMU and Penn research news articles in the T-SET blog and newsletter.
• Feature article of the UTC in the CMU ICES quarterly magazine.
• Worked on developing Marketing and Communications plan.

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 January – July 2013. Click on hyperlink to view articles.

**Articles:**
- Will Government Regulations Crash Driverless Cars? *The Daily Caller*
- Traffic changes yield savings in Cranberry. *The Pittsburgh Post-Gazette*
- Traffic flow is no accident in Cranberry. *TribLive*
- Cranberry touts signal savings. *Cranberry Eagle*
- To Cut LA Traffic Woes, City Installs Synchronized Traffic Lights. *Mother Nature Network*
- IBM to Pittsburgh: Use data to help motorists get around. *TribLive*
- 18 Brilliant Ways To End Gridlock And Save Billions. *Business Insider*
- Whatever Happened to the Power of 32. *PopCity Media*
- Engineering and Design schools partner with Carnegie Mellon to research transportation. *The Daily Pennsylvanian*
- PennDOT prepares for advent of autonomous vehicles. *TribLive*
- Penn drives transportation research forward. *PennCurrent*

**Videos:**
- CMU Working on Vehicle that Can Drive Itself. *WTAE*
- Driverless car steering course to road-readiness. *Reuters*

3. Participants and Other Collaborating Organizations

T-SET Advisory Council

The T-SET Advisory Council has started to work with T-SET managers to strategically grow the UTC. Each Advisory member has been engaged in a one-on-one conversation, prior to convening this fall to determine “what we want to be when we grow up.”

The individual members also provide significant collaboration opportunities with their extensive professional affiliations. A few examples:
- Kirk Steudle chairs TRB’s Strategic Highway Research Program II, is Vice Chair of TRB’s Executive Committee and immediate past President of AASHTO.
- Barry Schoch is a current AASHTO Board member.
- Beverly Scott and Joseph Casey are members of the APTA Executive Committee and Bavi is past Board Chair.
- Gerry Mooney, Bob Skinner and Kirk Steudle are members of the ITS America Board.

T-SET Consortium. In May 2013, we held a Consortium Meeting on CMU’s campus. The meeting focused on deployments and test beds that were working in concert with Consortium members, future research work in partnership with PennDOT, Education Workforce and Technology Transfer at the UTC, and was followed by a Plenary Session where the following questions were asked:

- What skills would you want if you were hiring an undergrad from CMU or Penn? How about a masters or doctorate graduate?
- If you were designing a course curriculum at Penn or CMU, what would it include?
- What would you want to include in a short course?
- Talk about two transportation related problems that would be helpful to your agency or company if they could be solved.

Appendix A – Research Projects Accomplishments, Products and Participants

Thrust Area #1 In-Vehicle Technologies for Safety

*V2V for Safe Intersections (DOT Goal: Safety; Topic: Technology Related Research)* Lead: Ozan Tonguz (CMU)
Other products: 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). 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.

- Video product: A video clip that demonstrates benefits of this project has been prepared and aired in January 2013 by the Discovery Channel Canada. The video clip can be found at http://watch.discoverychannel.ca/c/dl841424#clip841424

Collaborators: Walantwri Vnyasikuru, Research Scientist, and Carnegie Mellon University
- Apoor Khandelwal, Masters student, Carnegie Mellon University

Impact on Principle Discipline: Below, we briefly elaborate on these outcomes from the program and how they impact on the base of knowledge, theory, and research in the transportation research.

1. The impact of RF obstructions at the intersections on the proposed Virtual Traffic Light (VTL) scheme has been studied carefully and have been published.

2. The important issue of how to support priority management at intersections with the proposed VTL scheme has been studied and the results have been published. The main findings show that by designing a new biologically inspired algorithm VTL can give priority to vehicles at intersections. This has 2 concrete applications:
   i) Emergency vehicles such as ambulances and fire trucks can be prioritized with the proposed VTL scheme. This can save lives in emergency situations such as traffic accidents or fires in buildings.
   ii) Mass transit vehicles (such as buses) can be prioritized at intersections during rush hours. This is a very desirable result since prioritizing mass transit vehicles at the intersections could reduce the commute time of a larger number of urban workers during rush hours.

It is our belief that both of these applications are significant safety applications, which will enhance the appeal of the biologically-inspired scheme known as Virtual Traffic Lights.

3. Large-scale simulations based on a modified version of the SUMO simulator were run to quantify the benefit of the proposed VTL scheme in the city of Pittsburgh during rush hours (both morning and evening rush hours). 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.

4. New work on showing how Virtual Traffic Lights fare with respect to congestion pricing has been finished and a report has been prepared. Part of this work will be submitted as a CMU patent through the Technology Transfer Office of CMU.

The main finding here is to show that, contrary to common belief, Congestion Pricing cannot effectively mitigate or eliminate congestion. Conversely, it is shown that Virtual Traffic Lights is a much more effective scheme compared to Congestion Pricing. These findings should be of interest to the US Department of Transportation (DoT) in addition to companies such as IBM who implement congestion pricing in cities like London in the U.K. and other companies such as Xerox who also are involved in congestion pricing in cities like Atlanta and Los Angeles.

Impact on other Disciplines: Some of the work that was done in the context of Virtual Traffic Lights is also relevant for traffic control in railway transportation. Based on this synergy, new contacts have been established with Bombardier. There is a great deal of interest on the part of Bombardier to support my research and to license some of the patents we have filed on VTL and traffic control in railway transportation. In fact, effective January 2013 it has been agreed that Bombardier will sponsor my research for railway transportation. Some of the work that have done in this domain was reported in the following paper:


Website: [http://utc.icscmu.edu/utc/projectItem.asp?ID=51](http://utc.icscmu.edu/utc/projectItem.asp?ID=51)

Technologies or Techniques: We have developed algorithms that process representations from multiple external sources of information. These representations provide contextual information that describe if and where certain objects are likely to occur in a scene. Basically, these representations can be used to obtain a priori on the set of possible object occurrences, object locations and scenes. The advantage of using these representations is that any prior knowledge of the environment is used to understand the scenario in which drivers and vehicles operate. For example, the information contained in a city map can be used to obtain priors for potential occurrences of buildings and street for a given location. We have developed approaches that allow the use of external sources of information to improve the performance of scene understanding algorithms using images. In particular, we have demonstrated our approach using street map information to improve the accuracy of a semantic labeling system in 2D. These
approaches are described in an article—currently in preparation—that will be submitted to the "IEEE Winter Application and Computer Vision Conference 2014" in August.

**Other products:** Developed a Software API that allows users to obtain map information over the internet, and export it to other environments (e.g. Metri). We have shared this API with other UTC projects, in particular, "Continuous Road Surface Distress Detection".

**Collaborators:** Discussion with researchers from Takata (TK Holdings Inc., Gibsonia, PA). They have agreed to support our research by providing us with stereovision data obtained from one of their products.

**Impact on principle discipline:** The algorithms that we have developed will allow researchers and practitioners to use information from multiple sources in applications such as pattern recognition, object detection and classification, and scene interpretation, without complex modifications. Additionally, these algorithms have the ability to improve the performance, in terms of accuracy and reduction of computational load, of current pattern analysis and recognition techniques. In the transportation domain, these improvements will facilitate the incorporation of these technologies into common vehicles, which in turn will enable the deployment of driver assistance systems that are capable of generating warnings, making recommendations, or taking corrective actions, thereby increasing the driver’s safety.

**Goal and Timeline for Deploying This Technology:** Submit paper to "IEEE Winter Application and Computer Vision Conference 2014" by end of August 2013. Demonstration of prototype application, October 2013.

**Sensory Augmentation for Increased Awareness of Driving Environments:**

**DOT Goal:** Safety; **Topic:** Technology-Related Research; **Lead:** John Dolan and Paul Rybski (CMU)


**Technologies and Techniques:** We have developed: 1) a probabilistic method for estimating the intent of other drivers; 2) vision-based algorithms for identifying and classifying persons, bicyclists, and vehicles; 3) safety verification methods for emergency automobile maneuvers.

**Impact on the development of the principal discipline:** Automated intent recognition for automotive applications has the potential to greatly improve safety systems in cars and on roadways. If a situation around the vehicle can be deemed potentially hazardous due to the driving conditions, actions of other drivers, the speed of the vehicles, and existence of blind spots, then automated systems can alert the driver to this before an unavoidable hazardous situation can occur.

**Goals and associated timeline for deploying this technology:** By early fall 2013, deploy the entrance-ramp and lane-change behaviors on our autonomous Cadillac SRX. Once the autonomous behaviors are validated, they can be scaled back/translated into semi-autonomous alerts for drivers.

**AutoPlug: An Automatic Testbed for Remote Electronic Controller Unit Diagnostics, Testing, and Verification**

**DOT Goal:** Safety; **Topic:** Technology; **Lead:** Rahul Mangharam (Penn)

**Publications:** Type: Journal; Author(s): Rahul Mangharam Title: The Car and the Cloud: Automotive Architectures for 2020 Journal: National Academy of Engineering, The Bridge on Frontiers of Engineering Volume: 42 Year: 2012 Page numbers: 9, Status of publication: Published, Acknowledgement of federal support: Yes.

**Websites:** whw.automplug.org

**Technologies:** We have developed AutoPlug, an automotive Electronic Controller Unit (ECU) test-bed to diagnose, test, update and verify controls software. AutoPlug consists of multiple ECUs interconnected by a CAN bus, a vehicle driving simulator which behaves as the plant model and a vehicle controls monitor for system identification, diagnostics and remote programming of ECUs. AutoPlug is focused on addressing software-related recalls for vehicles.

**Products:** Hardware and Software for Test-bed available at http://www.automplug.org

**Collaborators:** Delaware Valley Regional Transportation Commission (DVRPC) - Collaboration on Philadelphia Center City traffic signal scheduling

**Impact on Principle Disciplines:** Open Automotive Architecture for Plug-n-Play Services

In 2010, over 20.3 million vehicles were recalled. Software issues related to automotive controls such as cruise control, anti-lock braking system, traction control and stability control, account for an increasingly large percentage of the overall vehicles recalled. There is a need for new and scalable methods to evaluate automotive controls in a realistic and open setting. We have developed AutoPlug, an automotive Electronic Controller Unit (ECU) test-bed to diagnose, test, update and verify controls software. AutoPlug consists of multiple ECUs interconnected by a CAN bus, a race car driving simulator which behaves as the plant model and a vehicle controls
monitor in Matlab. As the ECUs drive the simulated vehicle, the physics-based simulation provides feedback to the controllers in terms of acceleration, yaw, friction and vehicle stability. This closed-loop platform is then used to evaluate multiple vehicle control software modules such as traction, stability and cruise control. With this test bed we are able to develop ECU software diagnosis and testing to evaluate the effect on the stability and performance of the vehicle. Code updates can be executed via a smart phone so drivers may remotely "patch" their vehicle. This closed-loop automotive control test bed allows the automotive research community to explore the capabilities and challenges of safe and secure remote code updates for vehicle recalls management.

In the past year, we have extended AutoPlug to include Adaptive Cruise Control (ACC) (for details see http://autoplug.blogspot.com/) to evaluate control algorithms and security attacks on ECUs. We have been able to successfully demonstrate the effect of sensor noise, limited field of view and other non-idealities on the performance of ACC. We have demonstrated this to the U.S. Department of Transportation, Research and Innovative Technology Administration, John A. Volpe National Transportation Systems Center. We have also demonstrated this to Intel Corporation, Toyota Infotech Center, BOSCH Research and General Motors.

Awards: The AutoPlug project won the Grand Prize in the World Embedded Software Contest, Seoul, Korea in November 2010.

NOTHING TO REPORT

SEPTA GIS: Visualization and Analysis of Railway Safety Incidents (DOT Goal: Safety; Topic: Technology) – Lead: Camillo J. Taylor (Penn)
COMPLETE. Final report to be posted on website when editing complete.

Bus Pedestrian Collision Warning System (DOT Goal: Safety; Topic: Technology) - Lead: Daniel Lee (Penn)
Technologies or Techniques: Visual processing algorithms are open-source, and freely available
Other Organizations Involved as Partners: The Southeastern Public Transportation Authority (SEPTA)
Other Collaborators: Jim Fox - Program Leader, Director, System Safety & Risk, SEPTA; Scott Sauer - Safety Expert and Source for Accident Data, Manager, Operational and Occupational Safety, SEPTA
Impact on the Development of the Principle Discipline: The ARM based embedded system requires no modification on the bus hardware and also well fits the budget requirement. The pure GPS based turning detection algorithm can detect bus turning with fixed route while IMU and GPS data fusion expands its detection ability to general cases. LIDAR based pedestrian detection system on the other hand, generate a real time occupancy map of current environment and has an ability to find any obstacle front in the certain range. The combination of audible and visual warning has been proven to be the most effective and robust warning approach from Pedestrian surveys. Students have been trained to conduct human subject experiment and closely working with local transportation authority.

Goals and associated timeline for deploying this technology: The ultimate goal for the Pedestrian Collision Warning for Buses project is to develop commercially feasible devices for transportation authorities to mitigate bus-pedestrian accidents. In order to accomplish that goal, following schedule has been associated for deploying this technology July 2013 - Sep 2013: Online detection algorithm for bus turning Oct 2013 - Dec 2013: LIDAR based detection for actual pedestrian Jan 2014 - Mar 2014: Turning detection and pedestrian detection combination and proper warning trigger research Apr 2014 - Jun 2014: Test whole system on bus

A Model for Enabling Trustworthiness in V2V Networks (DOT Goal: Safety; Topic: Technology-Related Research) – Lead: Insup Lee (Penn)
Website: http://precise.seas.upenn.edu/research/automotive/v2v/
Technologies or Techniques: We have proposed a novel trust management framework for ensuring trustworthy traffic incident report using Vehicle-to-Vehicle (V2V) networks. Accident report messages being received can be evaluated regarding their trustworthiness through explicit feedback mechanism or auto-correlation with authoritative dataset, with the benefit of hindsight. Such historical behavior information of message sender will be used to compute a trust value for trust decision making by the receivers of the message in real-time. Further, static information about the message sender such as vehicle maker, vehicle model, and spatial and
temporal context information is also considered to reason about trust and to achieve trust decisions. For validating our scheme, we implemented a V2V/V2I trust simulator by extending an existing V2V simulator with trust management capabilities. Preliminary analysis of the model shows promising results.

Other products: A V2V/V2I trust simulator (software) significantly extended based on an open-source hybrid-network simulator – GrooveNet.

Other Organizations Involved as Partners: Since there was no space under "What individuals have worked on the program?" I added my postdocs and students who have been working on this project on this space. Nothing to report in "What other organizations have been involved as partners?" Name: Inup Lee Program/Project Role: Project leader (Caltech Filter Moore Professor at the University of Pennsylvania) Contribution to Program/Project: Leading the research team. Collaborated with individual in foreign country (Y/N): N Name: Krishna K. Venkataraman Program/Project Role: Project member (Postdoctoral Researcher at the University of Pennsylvania) Contribution to Program/Project: Designing the system framework and workflow under the collaboration with other project members. Collaborated with individual in foreign country (Y/N): N Name: Jan Churg Program/Project Role: Project member (Doctoral Student at the University of Pennsylvania) Contribution to Program/Project: Designing the system framework and workflow under the collaboration with other project members. Collaborated with individual in foreign country (Y/N): N Name: Cong Liao Program/Project Role: Project member (Master Student at the University of Pennsylvania) Contribution to Program/Project: Conducting experiment and programming under the collaboration with other project members. Collaborated with individual in foreign country (Y/N): N Name: Noor Bazzou Program/Project Role: Project member (Postdoctoral Fellow at the University of Pennsylvania) Contribution to Program/Project: Conducting experiment and programming under the collaboration with other project members. Collaborated with individual in foreign country (Y/N): N Name: N

Impact on the Development of the Principal Discipline: Improve the state-of-the-art of trust management in vehicular networks, poster presentation and academic paper submission at international conferences. Support and train graduate students and postdoctoral researcher. Release software experiment platform to support further research.

Goals and Timeline for Deploying This Technology: 2013: 1. Study and improve the communication overhead, the cost of infrastructure deployment and the effectiveness of trust modeling in our current trust modeling approach and trust protocol design. 2. Improve our simulator implementation and using its capability for a more thorough analysis of the proposed approach and comparing with existing trust management proposals for vehicular networks. 2014: 1. Study autonomous safety features for car accidents avoidance. We are interested in detecting faults and cyber-attack vectors that could compromise the safety of a vehicle and the surrounding vehicles and environment. Lately we have been witnessing an increase in autonomous vehicles: most of the cars we drive nowadays use multiple sensors to maintain constant speed (e.g., adaptive cruise control), avoid obstacles and collisions, park, move autonomously through traffic, and improve the overall driving comfort. Several of these applications require vehicle-to-vehicle coordination. In the presence of a cyber attack in which the received information from other vehicles is compromised, safety is also compromised. Thus, our goal is to develop resilient frameworks to guarantee vehicular safety in the presence of malicious cyber attacks.

Toward a Smart Automotive Headlight for Seeing Through Rain and Snow (DOT Goal: Safety; Topic: Technology-Related Research) – Lead: Srinivasa Narasimhan (CMU)


Website: Smart Headlight Website: http://www.cs.cmu.edu/~LLM/projects/IL/smart-headlight This website summarizes the project and presents all results to-date since 2012.

Technologies or Techniques: Novel technology and design for vehicular headlights of the future that make driving less stressful and more safe.

Other products: The Smart Headlight website provides several videos of the system working. The prototype headlight is also a tangible hardware product developed under this project.

Other Organizations Involved As Partners: Intel Science and Technology Center - Embedded Computing

Other Collaborators: individuals working on the project: Prof. Srinivasa G. Narasimhan (PI) Prof. Takeo Kanade Prof. Anthony Rowe Dr. Robert Tamburo (Project Scientist) Dr. Erik NuruVadi (Intel) Dr. Mei Chen (Intel). Other collaborators working with PI on algorithms that will be transferred to this project: Yuandong Tian (PhD student) Supreet Achar (PhD student)
Impact on the Development of the Principle Discipline: The concept of a smart headlight that is highly flexible and programmable for many tasks that help the driver is the first-of-its-kind and has the potential to spur research in the fields of computer vision and digital imaging, illumination, and displays. The project has given rise to a new sub-area called Reactive Visual Systems that merge ideas from imaging design and Computer Vision. The project is very interdisciplinary in nature with components from systems engineering, hardware design, embedded computing, computer vision, and imaging design. As such, the participants in the project come from a variety of fields such as electrical engineering, computer science, optics, and robotics.

Impact on Other Disciplines: The potential impact of our headlight system that enhances safety of drivers and vehicles in stressful situations such as rain and snowstorms at night on intelligent transportation systems is significant.

Goals and Timeline for Deploying This Technology: The long-term goal is to install these headlights in all vehicles. This is an ambitious project and we have made strong strides in two years since we started this project. We will need three more years to complete a working prototype on a vehicle. After this, we will work with US NHTSA on regulatory issues and commercialization with automotive manufacturers and Tier 1 companies. This is expected to take 3-5 years.

Thrust Area #2 Smart Infrastructure

Smart Parking (DOT Goal: Livable Communities; Topic: Land-Use Planning) – Lead: Robert Hampshire (CMU)

Website: www.parkpgh.org

Publications: Type of publication: Journal, Authors: Robert Hampshire, Tayo Fabusuyi, Title: Decision Analytics for Parking Availability in Downtown Pittsburgh, Journal: Interfaces, Status of publication: Under review, Acknowledgement of federal support: Yes

Type of publication: Conference paper, Authors: Tayo Fabusuyi, Robert Hampshire, Victoria Hill, Title: Evaluation of a Smart Parking System, Journal: Transportation Research Board of the National Academies of Engineering, January 2013, Status of publication: Accepted, Acknowledgement of federal support: Yes

Type of publication: Conference paper, Authors: A. Millard-Ball, R. Weinberger and R.C. Hampshire, Title: Is the glass 83% full or 15% empty? Assessing the efficacy of San Francisco’s parking experiment, Journal: Transportation Research Board of the National Academies of Engineering, January 2013, Status of publication: Accepted, Acknowledgement of federal support: Yes

Other Organizations Involved as Partners: We conducted a stakeholder and community parking survey of the following organizations. Numerit LLC, Deep Local LLC, and ALCO parking, East Liberty Development Corporation, Oakland Transportation Management Association, Pittsburgh Parking Authority and the City of Pittsburgh Transportation Planner.

Continuous Road Surface Distress Detection (DOT Goal: State of Good Repair; Topic: Infrastructure Monitoring Research) - Lead: Christoph Mertz (CMU)

Website: http://utrc.ices.cmu.edu/utrc/item.aspx?ID=57; http://utrc.ices.cmu.edu/utrc/Mertz%20project%20description.pdf

Technologies or Techniques: The technologies that are being developed in this research activity are data collection with a smartphone, analysis of collected images and other data, display of the data to the user and software to automate the whole process. The current status is that the first version of the smartphone data collection is completed and is about to be tested in a pilot test. The data can be displayed on Google Earth. We also have preliminary image analysis software.

Inventions, patent applications, and/or licenses: An invention disclosure has been filed with the CMU tech transfer office for the smartphone based data collection software. It is being licensed as open source software.

Other products: Research Database: Road images and videos tagged with GPS, time, and acceleration in and around the City of Pittsburgh. Data has been collected for a full year.

Other Organizations Involved as Partners: City of Pittsburgh, Department of public works: We have meetings with their maintenance division to study their work practices and get feedback on our results. We are starting a pilot test with them in which they test our system. Personnel exchange: One of our undergrads has a part-time internship with the City of Pittsburgh during this summer. Cartograph (infrastructure management software vendor) will collaborate with us and the City of Pittsburgh on the pilot test.

Impact on the Development of the Principle 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 fields 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 citywide databases of images (e.g. Google Streetview). With such databases new "big data" research will be possible in the fields of computer vision and transportation.

Goals and Timeline for Deploying This Technology: While all tasks mentioned as part of this project are completed, the team is in the process of preparing a final journal publication on the topic of "congestion management, environmental measures and safety". This goal is to submit this paper for the TRB 2014 conference and TRR publications.
Bridge Monitoring (DOT Goal: State of Good Repair; Topic: Infrastructure Monitoring) - Lead: Jacobo Bielak (CMU)


Technologies or Techniques: This funding has allowed us to further explore new signal processing approaches for determining if a bridge is healthy or damaged, work which we have continued over the past semester. Major accomplishments of this system were the application of cross-correlation function to analyze new data we collected from experiments on the parking garage structure. In addition, we have performed more fundamental research on how to use graphical modeling to interpret Structural Health Monitoring data, and have used principal component analysis to examine regression data. Are supplementing this work with an analytical/numerical approach using a simple model to help in the interpretation of the experimental results.

Other Organizations Involved as Partners: Core participants at CMU Faculty: Bielak, Garrett, Kovacevic, Nch Students: Chen, Lederman, Wang.

University of Pittsburgh, Pittsburgh, PA. Through collaborator Piervencenzo Rizzo, a faculty member in the Civil and Environmental Engineering Department. (2) In kind support (4) Collaborative research: National Science Foundation, Arlington, VA. Through grant 1130816, "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: We have begun working with the Pittsburgh Port Authority, to instrument light rail commuter trains. So far we have had two successful meetings, and have purchased the components we plan to install on their trains. At the core of this project, we have collaborated between Civil and Environmental Engineering (Faculty: Bielak, Garrett; Students: Carda, Lederman, Wang) and Biomedical Engineering and Electrical and Computer Engineering (Faculty: Kovacevic; Student: Chen). We have collaborated with Christoph Martz 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. Martz is himself involved in other projects with the UTC. We have collaborated with Piervencenzo 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 investigate new signal processing techniques that have advanced the sophisticated yet economical structural health monitoring technique our group has been developing. Second, this grant has helped train civil engineering students to learn more about signal processing, while enabling signal processing students, to examine applications in Infrastructure. This past semester we have made significant progress on how to determine the severity and location of damage. We have been applying new algorithms to data we collected this spring on the lab scale model. So far, we have tried several different feature extractors and classifiers to (1) study the potential power of each algorithm, (2) find suitable situations in which to use each algorithm, (3) study the complexity of the classification problem and (4) upgrade our classification system to achieve better results. For damage classification, we found that Sparse Representation Method is more powerful than the Fourier Discriminant Method, in terms of achieving higher accuracy with fewer labels. For damage severity and location regression, we use both principal component analysis (PCA) and independent component analysis (ICA) to extract features and kernel linear regression algorithm to test the validity of the feature selection method. The majority of this work will be presented at the IABMAS conference in 2014 which is the premier conference for Structural Health Monitoring. This research continues to push the boundaries in terms of the sophistication of bridge structural health monitoring.

Impact on Other Disciplines: The signal processing techniques researched under this grant were recently presented at a prominent signal processing conference (ICASSP). We have recently submitted a paper based on this work to the premier IEEE journal in the signal-processing field. The paper has been assigned to an Associate Editor and is currently under review. Signal processing within the civil engineering discipline is a nascent field, and even though the techniques we are applying are new for this type of indirect Structural Health monitoring, they have been proven in other areas of signal processing. We expect this project will generate more interest within the signal processing community for studying structural health monitoring and other infrastructure-related applications. New approaches in signal processing have been at the heart of some of the most impressive technological advances of the last
decade, in fields such as wireless communication, biomedical imaging and speech recognition. Based on our current results, we can foresee that the application of signal processing techniques to civil engineering will play an important role in providing safer, smarter infrastructure networks for future generations.

Goals and Timeline for Deploying This Technology: Our main goal for this project is to develop a prototype bridge condition detection methodology that will help identify damage states in realistic situations. We expect to deploy such a prototype system by the end of the currently funded project in 2014.

Real-Time Bus Recognition for Adaptive Signal Control (DOT Goal: Livable Communities; Topic: Technology) - Lead: Steve Smith (CMU)

Publication: Type: Conference Paper Authors: Smith, Stephen F., Gregory J. Barlow, Xiao-Fen Xie, and Zachery B. Rubinstein Title: SURTRAC: Scalable Urban Traffic Control Journal: Compendium of Papers of the 32nd Transportation Research Board Year: 2013
Website: www.surtrac.net - this site contains descriptions and research progress updates on current work on adaptive traffic signal control, including current UTC research on real-time bus recognition and efforts to integrate with the SURTRAC Adaptive Traffic Signal System.

Technologies or Techniques: SURTRAC - A real-time, adaptive traffic signal control system. Based on an integration of concepts from artificial intelligence and traffic theory, SURTRAC is designed specifically for optimization of urban road networks, where there are multiple, conflicting dominant flows that shift over time. SURTRAC was initially deployed and field-tested on a 6-intersection grid in East Liberty, showing 25% reduction in travel times, 40% reduction in wait time and a projected 21% reduction in emissions. We are currently expanding the pilot test site to include 9 additional intersections, and have plans to further expand to a total of 45 intersections by the end of 2014. Real-time bus detection - We have developed an initial recognizer, based on use of support vector machine (SVM) learning technology, that extracts images from real-time video camera feeds. In laboratory tests, it exhibits near 100% accuracy on close-up bus detection and degrades as the distance to the intersection increases. Over the next 6 months, we intend to improve its efficiency and field test it on an appropriate intersection at the East Liberty deployment site. The goal is to provide passive detection of buses for use within the SURTRAC adaptive signal system.

Other Organizations Involved As Partners: City of Pittsburgh Department of Public Works - The City has assisted in the initial pilot deployment of SURTRAC, and is currently installing detection and communication hardware to enable the current expansion of the SURTRAC deployment to 19 intersections. The City has also facilitated capturing of representative images from the East Liberty site to enable development and training of a real-time bus recognition system. FLIR Traffic - FLIR 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.

Other Collaborators: The real-time bus recognition system is being developed by Aravind Mahendran, a Master 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.

Impact on the Development of the Principle 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 SURTRAC adaptive system deployment, is discoving this misimpression 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. Congestion costs in US urban areas (in terms of time lost and fuel consumption) are estimated to be $108 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.

Goals and Timeline for Deploying This Technology: Our major goal for the year is to field test a system for real-time recognition of buses from commercial grade video camera streams. In the first 6 months of the project we have developed a recognizer that accurately detects buses close to the intersection and operates in under a minute. Our current work is focused on: (1) Improving accuracy at greater distances from the intersection through analysis of temporal sequences of images and (2) reducing the number of
exemplars considered during recognition to enable real-time computation. Once these tasks have been accomplished, we will configure an executable that can run locally at the intersection, and we will proceed to evaluate real-time recognition performance.

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

Open Source Vehicle Tracking System (DOT Goal: Safety; Topic: Technology-Related Research) – Lead: Camillo Taylor (Penn)

Technologies or Techniques: We are currently working on improving and refining our approach to image based vehicle detection and tracking so that it can be tested by our collaborators at DVRPC.

Other Organizations Involved As Partners: DVRPC - Delaware Valley Regional Planning Commission

Impact on the Principle Discipline: What we are currently working on is developing techniques for vehicle tracking that are both effective and computationally tractable. To do this we have been looking at methods to analyze the spatio-temporal signals derived from an initial background segmentation of the video imagery. Our hope here is to develop systems that can accurately detect segment moving vehicles through an analysis of the spatio-temporal signatures they induce. Our aim is to develop schemes that are computationally efficient so that they could ultimately be deployed on relatively inexpensive smart camera platforms. This would reduce the cost of deployment and allow us to gather traffic data from many locations in real time. In the course of this project we have involved 3 masters student from Penn and one undergraduate from U.C. Berkeley who is currently working as a summer intern.

Impact on Other Disciplines: Methods used in our research and studies can be used by economists, engineers and planners.

Goals and Timeline for Deploying This Technology: Our plan is to develop a second prototype system which we can share with our partners at DVRPC by the end of the summer. We would then like to refine our algorithms and the user interface based on their feedback with a view to developing a tool that they can use in practice.

Modeling, Verification and Validation of Transportation Safety (DOT Goal: Safety; Topic: Technology-Related Research) - Lead: Andre Platzer (CMU)


Website: http://symbolics.com/info/DCCS.html

Other products: 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.

The textual modeling editor supports creating hybrid systems specifications in dL with syntax highlighting, code completion, refactoring operations, templates, cross referencing, and model outlines. It is built using Eclipse technology (EMF, Xtext) and bases on the grammars of KeY and dL. The KeYmaera prover can be run directly from within the modeling environment. The dL graphical modeling editor supports creating hybrid systems specifications with UML profiles. Graphical models can be translated into textual models and loaded into KeYmaera. The graphical modeling editor is built using Eclipse technology (EMF, Papyrus). The dL proof versioning and comparison complements the dL textual modeling editor with collaboration support. Specifically, it allows modelers to share (uncompleted) proofs via a source code repository and compare different versions of a proof both in a textual and graphical manner. Proof comparison detects and highlights newly added proof branches, deleted branches, and conflicts in case a proof was extended concurrently.
Other Organizations Involved as Partners: Individuals on the project Organization: Carnegie Mellon University, School of Computer Science (Computer Science Department) Name: Aram Ebleker Role: Junior Student Contribution: Education Name: Sarah Loos Role: Co-author Contribution: Verification of wireless V2V communication Name: Stefan Mitsch Role: Co-author Contribution: ShL graphical modeling editor, collaborative verification, co-author on research paper Name: Khail Ghorbal Role: Co-author Contribution: co-author on research paper

Impact on the Principal Discipline: 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 items, as family cars are equipped and sold with these devices. However, with this increased complexity, it is far more challenging to ensure the safe and accurate functioning of these devices, especially in 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, to those that are not envisaged 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 to prove a counterexample. 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 systems 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. System models for KeYmaera can be created with Sphinx, a freely available textual and graphical modeling tool that supports syntax highlighting and checking, code completion, and model and proof exchange. Through Sphinx, domain experts can create verification tools for complex problems and get help from verification experts (published at the 2013 AISB Workshop on Enabling Domain Experts to use Formalized Reasoning). In this effort, we collaborated with visiting postdoctoral researcher Grant Olney Passmore. As a case study in hybrid system verification, we model obstacle and collision avoidance of autonomous vehicles, and prove that these vital safety systems of autonomous vehicles fulfill several safety properties. We formally study two safety properties of avoiding stationary and moving obstacles (e.g., parked vehicles, buildings, pedestrians, and other vehicles driving on the road). Passive safety ensures that no collisions can happen while the vehicle moves, i.e., if a collision occurs at all then only when the vehicle is stopped and other (moving) obstacle ran into it. The difficulty with passive safety is that it still allows the vehicle to stop in unsafe places, creating unavoidable collision situations in which other entities on the road have no control choices left that would prevent a collision. With the stronger passive friendly safety, a vehicle additionally maintains sufficient maneuvering distance for others to avoid collision as well. Moreover, we formally prove that safety can still be guaranteed despite location and actuator uncertainty, as frequently (e.g., Imprecise GPS information, wheel slip during icy road conditions). These results are published at the 2013 Conference on Robotics, Science and Systems. In another case study in hybrid system verification, we formally studied distributed aircraft control. Not only is this case study an important contribution to safety in air transportation, its aircraft models also share dynamical characteristics with cars: the smooth dynamics of in-flight maneuvers are also required to model the curved motion of cars, which cannot instantaneously turn sharp corners. Thus, verification of curved flight maneuvers is a helpful step in the verification of (autonomous) vehicles and ground transportation. 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. Domain knowledge about those traffic control measures is provided by "team Communication Technology Management GmbH" (contact to the Austrian highways agency ASFINAG) in another collaboration. 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. Goals and Timeline for Deploying This Technology: As a pre-requisite for road traffic deployment, the goal is to adapt the models and proofs to the general operating conditions of roads. Although the models and proofs already account for real-world uncertainty of sensors and actuators in several ways, the behavior of obstacle avoidance is still too conservative for actual deployment, since very liberal behavior of other traffic agents is allowed in the models. On the one hand, such liberal modeling of traffic agents ensures maximum safety. On the other hand, it leads to rather conservative behavior of the autonomous vehicle. Real-world deployment will demand for different operating modes, depending on the current surroundings of an autonomous vehicle. For example, we would want to provide maximum safety and conservative behavior in school zones, but less conservative behavior when no other traffic participants are nearby. During the next project periods, we plan to make the models and proofs differentiable between operating modes that allow
fluent traffic, while at the same time ensuring high safety when it matters. Another goal is to further increase proof automation and modeling support in the tools that we developed in the course of this program. Manufacturers and traffic engineers shall ultimately be enabled to model and proof systems themselves. Inductive invariants are particularly important for proving traffic systems and particularly hard to discover (i.e., what does the system guarantee throughout its operations). At the moment, inductive invariants must often be specified manually. Our group is currently working on techniques to discover such inductive invariants automatically in many practically relevant models.

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

**Distributed Transit Rider Messaging (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research)** Lead: Aaron Steinfield (CMU)


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

**Technologies or Techniques:** The team has further developed SmartWrap, an extension of our existing Mixer system that focuses on the extraction of tables from the web. This work has involved a variety of tasks: test set development, interface development, algorithms development, implementation and testing. 

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

**Other Collaborations:** The team has described project activities with colleagues at Booz Allen Hamilton. There have been discussions and efforts to find new ways to collaborate on Tiramisu and SmartWrap.

**Impact on the Principle 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 not in use by other disciplines yet, SmartWrap has utility beyond transportation. It has drawn the attention of colleagues in medical records and other white-collar domains.

**Goals and Timeline for Deploying This Technology:** We hope to be populating the Tiramisu message stream with alerts from Port Authority of Allegheny County sometime this summer. This may be limited to internal versions of Tiramisu if the messaging update to the publicly deployed Tiramisu is not ready by then. The results for our human participant study on the web collection too for non-programmers will be prepared for publication later this summer. We are aiming for a conference paper submission in the fall.


**Technologies or Techniques:** Algorithms for traffic estimation, prediction and custom route assignment based on historic and real-time traffic data. We investigate this through the design of the AutoMatrix traffic simulator that is capable of simulating over 16 million vehicles on any US street map.

**Impact on the Principle Discipline:** Our goal is to investigate the construction, instrumentation and scheduling of time-bounded and anytime algorithms on multi-core architectures such as graphics processing units (GPUs). 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 monotonically increasing utility with the length of execution time. Such imprecise and approximate computing has wide application in prediction algorithms in the domains of vehicle traffic congestion, stock price prediction and weather prediction where a large number of variables and dynamical states must be considered to periodically stream an output. Our investigation focuses on time-bounded anytime algorithms on GPUs for real-time vehicle traffic congestion prediction and route assignment. To explore this, we have designed AutoMatrix, a traffic congestion simulation platform on the Nvidia CUDA-enabled GPU. AutoMatrix is capable of simulating over 16 million vehicles on any US street map and extracting traffic estimation, prediction and route assignment algorithms with high-throughput. This research has the potential to extend real-time scheduling on massively parallel GPU architectures to attack a variety of data-driven, interactive and dynamical algorithms with timely operation. We are now focusing on simulating large traffic networks for disaster response and evacuation. The goal is to evaluate evacuation approaches from traffic signal adaptation and with support of information dissemination using vehicle-to-vehicle networking. AutoMatrix now includes both simulation-based and optimization algorithms for vehicle traffic evacuation on real street maps. The software is open source and has been shared with collaborators in Cornell University and University of Connecticut. The PI is also on the Organizing Committee for the Delaware Valley Regional
Planning Commission for Disaster Response and Evacuation. The experience from this will contribute a real-world perspective on traffic evacuation to the project.

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

Other Organizations Involved As Partners: Delaware Valley Regional Transportation Commission (DVRPC) - Collaboration on Philadelphia Center City traffic signal scheduling

Other Collaborators: Emmanuel Anastasiadis <EANASTASIA@pa.gov> - Initial discussion on traffic congestion information sharing for AutoMatrix Project

ProtoDrive: An Experimental Platform for Electric Vehicle Energy Scheduling and Control - Lead: Rahul Mangharam (Penn)

Technologies or Techniques: ProtoDrive is 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. This platform allows for development of scheduling and control algorithms for the battery and super capacitor in electric vehicle powertrains to maximize range, improve battery lifetime and minimize peak current draw.

Impact on the Principal Discipline: ProtoDrive: An Experimental Platform for Electric Vehicle Energy Scheduling and Control In President Obama’s, Jan 2011 State of Union Address, he mentioned - “We can replace our dependence on oil with biofuels and become the first country to have a million electric vehicles on the road by 2015.” Electric Vehicles (EVs) have had a recent resurgence in popularity and are showing promise as a future mainstream means of transportation. However, the low energy density, high cost and long recharging time of batteries are formidable obstacles to mass consumer acceptance. There are a number of things that can be done to increase the viability of EVs such as: • Powertrain system optimization to extract the maximum range; • Development of better tools to predict range and reduce “range anxiety” • Optimal fuel control and driver behavior influence to increase range. An electric vehicle powertrain consists of all the components necessary to deliver power to the wheels. This typically consists of a battery, motor controller, motor, gear box and differential. Currently, EV powertrains are modeled and simulated in software and then prototyped and tested in a full-scale vehicle. While software can provide decently accurate predictions of performance, it may fail to miss some of the detailed intricacies of a real system. Full-scale models obviously demonstrate all real problems, however, iterating on a full-scale vehicle is time consuming and expensive. ProtoDrive is a small-scale electric vehicle prototyping platform that attempts to find a middle ground between simulating purely in software, and prototyping at full scale. It is a real hardware system, representative of a real powertrain, however, it is implemented at a scale small enough to fit on a desktop. The hope is that it will allow the quick and cost effective characteristic of simulating in software, while still being able to capture the intricacies of real hardware performance. ProtoDrive has a number of interesting applications that will further EV development. These include: • 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. ProtoDrive is 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. ProtoDrive can be used for a wide range of simulation tasks, and presently the benefits of a battery/super capacitor 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. http://protodrive.blogspot.com/2012/04/demo-day.html

To investigate battery-super capacitor 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 super capacitors 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/super capacitor system offers significant benefits over a battery-only system, by simulating real commuting routes in hardware.

Website: https://alliance.seas.upenn.edu/~mlabweb/dynamic/proto/

Other Products: Hardware and Software for Test-bed available at https://alliance.seas.upenn.edu/~mlabweb/dynamic/proto/

Awards ProtoDrive has been selected as a finalist in the 2013 Intel-Cornell Embedded Systems Cup Competition.
Analyzing Social Media for Improving Transportation Safety (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research) - Lead: Feng Chen, Ramayya Krishnan (CMU)

Publications: Conference Paper Authors: Feng Chen and Ramayya Krishnan Title: Adaptive Social Media Content Filtering using Transfer Learning Journal: ACM Transaction on Knowledge Discovery Year: 2013 Website: http://www.andrew.cmu.edu/user/fchen/index.htm

Other products: We are developing an online website for transportation safety enhancement using Twitter Data.

Impact on the Development of the Principal Discipline: We are developing a semi-supervised statistical model for social media content filtering. This work can be applied to other domains as well, such as medicine, public health, law enforcement, and security. The significance of our work is that our proposed model is able to adaptively learn patterns and extract meaningful information from social media, in which the language used is very informal and highly dynamic.

Goals and Timeline for Deploying This Technology: 1. We plan to finish the TKDD journal paper related to social media content filtering by the end of this month or early July. 2. We plan to complete the demo system and make it online by the end of this month or early July.

Enhancing the Safety of the Carnegie Mellon Campus for Blind Navigators (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research) - Lead: M. Bernardine Dias (CMU)

Website: [1] 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.


Technologies or Techniques: Work to date on the NavPal project has resulted in three primary technology tools: A smartphone app to give navigational assistance to blind adults as they move around unfamiliar indoor environments, an accessible online tool that allows blind adults to pre-plan routes in an unfamiliar indoor environment, and an online software tool for creating and editing building maps such that they can be easily made accessible to blind travelers.

[1] Smartphone app for navigation: Low-cost navigation solutions for indoor environments have a variety of real-world applications ranging from emergency evacuation to mobility aids for people with disabilities. Primary challenges for commercial indoor navigation solutions include robust localization in the absence of GPS, efficient route-planning and re-planning techniques, and effective user interfaces for resource-constrained platforms like smartphones.

[2] Online tool for pre-planning routes: Based on the feedback we received through our work with the smartphone navigation tool, we learned that many visually impaired people prefer to plan their travel before they leave their homes. To enhance the pre-planning capability of blind travelers, we prototyped a web tool to provide indoor navigation information that allows for pre-trip planning for indoor environments.

[3] Software for creating and editing accessible building maps: While exploring the different options to make indoor environments more accessible to blind travelers, we discovered that building managers do not have a standard or feasible method for creating and maintaining accessible indoor maps.

Other products: We have collected a significant amount of needs assessment data to support this project through our connections with local partner organizations and potential end users of the tools. We are working on reports and other means of sharing this information.

Other Organizations Involved as Partners: Western Pennsylvania School for Blind Children (WPSBC), Blind and Vision Rehabilitation Services of Pittsburgh (B VRS)

Other Collaborators: Given their work with smart cities, IBM is especially interested in exploring how some of IBM’s analytics tools can be used within the frameworks we create.

Impact on the Development of the Principal Disciplines: 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 has relevance in the areas of smart cities, navigation technologies, and user interface design.

Impact on Other Disciplines: Our work also impacts the overall dialog and relevant policies on accessibility in the digital age.
Goals and Timeline for Deploying This Technology: Our goal over the next year is to do more extensive user testing and corresponding enhancements of the more mature technologies in the tool suite we are developing, and deploy these tools to users in the following year.

Visual Navigation with Android Tablets (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research) - Lead: Daniel Lee (Penn)

Technologies or Techniques: The goal of this project is to develop an intelligent driver assistance system using Android tablets. Current vehicle navigation techniques rely solely on static road maps and noisy GPS data. This approach is prone to errors where GPS information is not available, such as urban canyons. We propose to use a windshield-mounted, Android tablet as a sensor platform for augmenting in-vehicle navigation. We have focused on developing algorithms to carry out key operations including the detection and tracking of dynamic elements (primarily moving vehicles on the road) and the detection and tracking of lane markings. Our algorithms are highly dependent on sparse salient features as they are better able to achieve real-time performance on the computationally constrained platforms we are working with. As such, we implemented and compared the performance of several feature detectors including: Features from Accelerated Segment Test (FAST), Binary Robust Independent Elementary Features (BRIEF), Oriented BRIEF (ORB), Harris Corners, Shi-Tomasi Good Features to Track, Maximally stable extremal region extractor (MSER), and SIFT Feature Detectors, as well as various Descriptors and Tracking/Matching Algorithms including the Lucas-Kanade Tracker (LKT) and template matching techniques. We concluded that a combination of the FAST corner detector, the BRIEF descriptor and template matching was most robust in terms of detecting the most features in the shortest times and matching feature correspondences between sequential frames across all datasets. We also developed a framework for detecting and tracking moving objects from our moving vehicle/platform. We modified a state-of-the-art monocular SLAM algorithm developed by George Klein and David Murray called Parallel Tracking and Mapping (PTAM) for accurate camera/vehicle pose estimation. The core of our moving vehicle detection algorithm consists of computing and comparing real and artificial optical flow fields. The real artificial optical flow field is computed using all the detected and tracked FAST-9 corners between pairs of images while the artificial optical flow field is based on vehicle egomotion estimates derived from the PTAM algorithm. Data from the accelerometer and gyroscope are fused with monocular camera data to refine pose estimates. Discrepancies in the magnitude and orientation between the two flows are used to identify potential moving pixels which are subsequently grouped into dynamic objects. To delimit road regions and further lower computational costs associated with feature detection, tracking and pose estimation, we have also designed algorithms to detect the ground plane and extract the horizon. For lane detection and tracking, we have implemented an algorithm that extracts long straight lines from road regions. Using our lane model, we can then track lanes throughout the video sequences using a Particle Filter. We are currently working on refining and optimizing our existing techniques and models and deploying and testing them on our mobile platforms. Future work would involve identifying pedestrians and cyclists in the vicinity of our vehicle as well as headway monitoring.

Other products: We are currently deploying and testing our techniques for vehicle and lane detection and tracking on Android tablets. The result will be an open source Android application to aid drivers in in-vehicle navigation.

Other Organizations involved as Partners: We are part of the Intel Science & Technology Centers (ISTC) Program - University Collaborative Research (Intel Labs). We are currently testing Intel's newly released Perceptual Computing SDK as well as their Creative Interactive Gesture Camera Developer Kit to investigate ways in which their software and camera can aid in developing personal computing technologies as well as augmenting our driver assistant system. We also share our results/progress in the form of technical reports/videos with other ISTC faculty.

Impact on the Development of the Principle Discipline: Android tablets are viable platforms for driver assistance systems because they are inexpensive, readily available and come with an array of useful sensors including GPS, color cameras, accelerometer, gyroscope, and wireless capabilities. Unlike many of the current advanced safety features available in vehicles today, this project does not require any specialized hardware to be installed on the vehicle. The radar and LIDAR sensors, typically used in modern vehicles, are expensive and any older vehicles would not benefit from these solutions. Our solution will not require any external hardware modification allowing for an immediate impact in both new and old vehicles. The techniques being developed for tasks such as lane markings detection and vehicle detection will add to the body of research and theory in Robotics and Computer/Machine Vision. Using the lightweight sensors aforementioned will provide insights in developing optimal vision and inertial-based solutions for computationally and resource-constrained devices such as mobile phones and tablets. These techniques can also be used in embedded computing systems of mobile robots and is also likely to increase real-time performance in tasks such as localization, route planning, mapping, navigation, and obstacle detection/tracking.

Goals and Timeline for Deploying This Technology: The ultimate goal is to develop an android application that can carry out real-time detection and tracking of road lane markings, vehicles and pedestrians, and perform headway monitoring in a variety of traffic scenarios. This system is expected to be deployed on our Android devices by July 31, 2013.
Multi-Camera System Based Driver Behavior Analysis (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research) - Lead: Jianbo Shi (Penn)

Technologies or Techniques: 1. Multiple camera system calibration and rectification toolbox. The MATLAB/C++ toolbox is able to calibrate various multiple camera system. The rectification is essential for disparity calculation and super resolution interpolation. 2. Disparity fusion algorithm for multiple camera system. The disparity algorithm utilizes redundant camera array system to get precise and occluded disparity map for object recognition and navigation.

Other products: 1. Several urban street datasets are built by camera array on the vehicle. The dataset contains buildings, traffic, and pedestrians in good and poor weather condition. Additional sensor data such as IMU, GPS, and LIDAR as well as driver’s behavior data from Kinect and views from camera glasses are synced. The dataset is valuable for driver behavior and safety research, visual SLAM and navigation research for mobile vehicles. 2. Multi-function data collection system. The system consists of camera array, IMU, GPS, LIDAR, Kinect and camera glasses within a vehicle, which is capable to simultaneously collect data of the street, driver’s behavior and driver’s view. The system utilizes ROS framework with reliability and expansion capability. It is the system to collect dataset for research. 3. Synchronized GoPro multiple camera array system. The system contains 13 GoPro Hero 2 cameras which is able to capture high-resolution video data on the street. Applications contain building surface reconstruction, pedestrian recognition and visual SLAM.

Other Collaborators: Jianbo Shi and Qiong Wang

Impact on the Development of the Principle Discipline: The urban street dataset is good research material to analysis driver’s intention and behavior. With the data of traffic, pedestrian, street, signs and buildings, as well as drivers reaction to the environment, the research could be meaningful to learn the correlation between behavior and traffic, and predict driver’s intention thus contribute to improve transportation safety.

Goals and Timeline for Deploying This Technology: Real-time implementation of intention prediction algorithm and test with different drivers by Year 2.

Thrust Area #5: Policy & Guidance

Assessment of Information & Communication Technologies in Transportation (DOT Goal: Livable Communities; Topic: Livability Performance Measures) - Lead: Chris Hendrickson (CMU)


Publications: Authors: Yeganeh Mashayekhi Title: Land Use and Congestion Management Strategies to Promote Urban Environmental Sustainability Year: 2013


Technologies or Techniques: Economic and environmental costs and benefits of a number of advanced control and communication technologies were assessed and measured by air pollution and greenhouse gas emissions using a consistent set of emission factors and analysis boundaries. Techniques used in this research looks at the holistic impact of the technologies on the environment and energy.

Other Organizations Involved as Partners: Organization name: Cranberry Township Location: Cranberry, PA In-kind support

Impact on the Development of the Principle Discipline: We have demonstrated approaches to incorporate a wide range of impacts in congestion management and other transportation measures including environmental and energy measures. Traffic delay reduction and environmental benefits were demonstrated around the Pittsburgh region. In addition our methods can be used to make decisions about infrastructure investments and management. Our analysis method has been published in the professional literature for widespread use. Project papers are already being cited and used.

Impact on Other Disciplines: Methods used in our research and studies can be used by economists, engineers and planners.

Goals and Timeline for Deploying This Technology: While all tasks mentioned as part of this project are completed, the team is in the process of preparing a final journal publication on the topic of "congestion management, environmental measures and safety". This goal is to submit this paper for the TRB 2014 conference and TRR publications.