Center for Embedded Systems (CES)
Request for Proposals Template – YEAR 8

DUE: FRIDAY, APRIL 15, 2016, by 11 p.m.

TITLE:	Environmental information and multi-sensor data fusion based performance estimations for smart cars				
PI:	Iraklis Anagnostopoulos	**EMAIL:**	iraklis.anagno@siu.edu	**TEL:**	(618) 453-7034
DEPT:	ECE	**SCHOOL:**	SIU		

ABSTRACT: (250 or fewer words)

The rapid growth of on-vehicle multi-sensor inputs along with off-vehicle data streams provides an opportunity for innovation in real-time decision making. The development of new advanced sensors is not sufficient enough without the utilization of enhanced signal processing techniques such as the data fusion methods. Multi-sensor data fusion (MSDF) is the process of combining or integrating measured or preprocessed data or information originating from different active or passive sensors. Besides the combination of sensors towards an automotive multi-sensor system, complex signal processing and sensor data fusion strategies are of remarkable importance for the availability and robustness of the overall system. As vehicles become autonomous with personal data platform concepts such as intelligent agents and hypervisors are critical for a robust foundation. A lean design becomes the spring-board for introducing future connectivity and mobility features in a scalable manner. In this project, we aim to develop and explore state-of-art data fusion techniques for decision making for automotive applications. Specifically we will combine the benefits offered by car's increased connectivity (e.g. internet, cloud services) with on-vehicle sensor information for providing detailed information about the state of the car and the environment.

PROBLEM:

Modern cars employ hundreds of sensors and electronic systems in order to obtain situational and environmental information (road grade, vehicle state, driver response) used to improve the drivers experience in performance, safety or convenience. Beyond the growth in tradition signals there is and will be a rapid growth in connectivity related information such as autonomous intelligent agents. Cars can utilize information from the internet, GPS, cloud services, other vehicles, and agents all in solitude for the most part. Data provided by these sources are affected by some level of impreciseness as well as uncertainty in the measurements including subjectivity or controversy. The situation increases in complexity with growth in new nodes (data sources) and thus corresponding explosion in data to be processed. For that reason, data fusion strategies are of remarkable importance for the availability and robustness of the overall system.

The automotive industry is always perusing avenues to improve driver safety. The advancement in technology regarding road and environment conditions provides an avenue for investing the data fusion related to traction control and the coefficient-of-friction. The friction between the tires of the car and the road determines the maximum acceleration, and more importantly the minimum stopping distance. A focus on the traditional and non-traditional sensors and data to estimate road slipperiness is a new area of investigation. Electronic control systems, like anti-lock braking system (ABS), participate in the vehicle control only when the maximum friction is exceeded. Future safety systems such as collision mitigation and vehicle-to-vehicle applications would benefit from a more continuous friction estimation system. As of today, a continuous estimation of road friction in the vehicles has not been solved. Stability systems (e.g. ABS) provide a good momentary estimation of the friction but this estimation is not valid if the conditions change. For example, coefficient-of-friction is affected by the type of tiers, the road condition and type, the weather, objects on the road (water, ice etc.), temperature, driver state, type of the car, weight, etc.

With the increasing number of information sources available in today's cars, estimation of friction coefficient is a challenge. Besides using only on-vehicle information, the car can also utilize information obtained by different sources (e.g. other vehicles, internet, historical data etc.). The proposed project aims at merging direct estimations with information from multiple on vehicle sensors as well as environmental information (other cars, internet) and employ efficient data fusion techniques. The innovative aspects of the project are many-fold:

1. Multi-sensor data fusion techniques will explore static and dynamic changes both on the vehicle and received from the environment. Specifically, the project will explore how these changes affect the decisions and the state of the smart car when some information is not available or when the environment changes rapidly (sensor/application failure, internet connectivity error etc.).
2. Employ reflective and deliberative information gathering. By being deliberative, an agent intentionally and selectively chooses how to gather information. By being reflective, an agent self-evaluates its informational needs and performance in order to understand its needs.
3. The estimation of friction coefficient will be used as a use case. Specifically the project will investigate how the estimation of coefficient of friction depends and varies on different information sources (sensors, vehicle-to-vehicle, information from cloud, historical data);
4. Propose an MSDF framework for fusing data from different types of sensors and inputs. Explore adaptive learning (historical data) methodologies and compare data and model driven techniques.

RATIONALE:

Sensor data fusion plays an important role in current and future smart cars. The development of new advanced sensors is not sufficient enough without the utilization of enhanced signal processing techniques such as the data fusion methods. A stand-alone sensor cannot overcome certain physical limitations as for example the limited range and the field of view. Therefore combining information coming from different sensors broadens the area around the vehicle covered by sensors and increases the reliability of the whole system in case of sensor failure.

Data fusion is not just an additive process. If successful, fusion should achieve improved accuracy (reduce the uncertainty of predicting the state or declaring the identity of the observed object) and more specific inferences than could be achieved using a single sensor alone. Multiple sensors can be arranged and configured in a certain manner to obtain the desired results in terms of sensor nodes or decision connectivity. The goal of this project is to obtain information from multiple and heterogeneous sensors and provide the necessary information to the car so as to have a clear image of the road conditions. For that reason, the use case that will be tested is the estimation of the coefficient of fraction.

CURRENT SOLUTIONS:

Data fusion is the process of combing information from a number of different sources to provide a robust and complete description of an environment or process of interest. Data fusion is of special significance in the automotive industry where a large amounts of data must be combined, fused and distilled to obtain information of appropriate quality and integrity on which decisions can be made.

Regarding coefficient of friction, the estimation methods proposed in the literature are classified into “cause-based” and “effect-based” approaches. “Cause based” estimations have two potential advantages: (i) the friction coefficient of the road surface ahead of the vehicle may be detected, which enables preview and preemptive actions; and (ii) estimation is possible without physical excitation, and could work well even when the vehicle is not being driven. These methods, however, only detect one aspect of road conditions. Therefore, other factors that affect tire force generation, such as tire types and wear/pressure, hydroplaning and change in normal load on driven wheels, are not taken into account. “Effect based” methods usually deal with physical characteristics of the car such as tire tread, tire motion, vehicle motion etc. These methods are more complicated and they rely on an explicit realistic model of the underlying processes and are generally successful if the assumptions are plausible and the model holds. However, “effect based” methods may not always be the best choice, for example, when the underlying model of the signals or the medium in which they propagate is too complicated, varying rapidly, or simply unknown.

Vision/Temperature Based Methods:

- Methods: Solutions presented in [1], [2] and [3] analyzed the texture of road images taken by camera to classify possible road types. The basic concept of these works is that the image of a rough surface has a wider distribution of pixel luminance levels than the image of a smooth surface.
- Problems: The performance of these vision-based methods is affected by the intensity and direction of light the reliability of the texture analysis deteriorates when the image is blurred by vehicle speed and vibration. Generally, vision information alone is not sufficient to estimate road conditions because many factors affect the road conditions which may not be easily discerned through this information exclusively. Therefore, when other pieces of information, such as sensors, weather conditions etc., are fused with vision information a more accurate estimate can be obtained.

Tire Tread Based Methods:

- Methods: Solutions presented in [4] **Error! Reference source not found.** and [5] estimated tire forces using tire carcass displacements measured by an LED sensor module. The measured signals were transmitted from the tires to the chassis through a wireless network. The displacement information was then processed and converted to tire force information that was being broadcasted through a CAN-bus. In [6], the authors use a sensor embedded in the tire and they present a tire-road friction coefficient estimation algorithm based on tire lateral deflection obtained from lateral acceleration. The lateral acceleration is measured by wireless 3D accelerometers embedded inside the tires.
- Problems: It is difficult to use these methods for production vehicles because of both the costs involved and technical challenges in embedding strain sensors and related power, signal conditioning and communication devices in tires. Also, these methods use only measurements from the vehicle sensors and cannot be applied to steady state driving conditions.

Wheel Dynamics Based Methods:

- Methods: Authors in [7] and [8] presented a road friction estimation method using wheel rotational behavior. When traction forces are applied to wheels, the resulting wheel speed difference between driven and non-driven wheels varies by road surface conditions. Consequently, road friction can be estimated. The same concept can also be applied during braking.
- Problems: The road friction estimation based on ABS/TCS excitations is generally inadequate due to controller intervention.

Table 1 Comparison of several estimation approaches [12]

Category	Special Sensors	Sensor reliability	Vulnerability	Cost	References
Vision/Temperature	Optical/Temperature	Need clear vision	Snow, ice	High	[1][2][3]
Tire tread	Strain sensor	-	Sensor noise	High	[4][5]
Wheel dynamic	-	-	High frequency disturbances	Low	[7][8][9]
Vehicle dynamics	D-GPS	Need line of sight	Slow reaction in rapid changes	Medium	[10]
	Inertial	-	Not good performance	Low	[11]

As it can be seen in Table 1, the coefficient of friction has been widely studied. However, each solution has its own limitations and assumptions and it is based on information provided by the vehicle. To the best of our knowledge, no work has combined information from external sources with on-vehicle sensors so as to further enhance the estimation of the traction of the car. Also, no research work has explored the impact of static and dynamic information sources for the estimation of the state of the car.

This project will focus on multi-sensor data fusion techniques over a multi-agent system that has been designed to provide service flexibility for modern cars. Specifically, the tested use case will be the estimation of coefficient of friction. The differentiators of this project compared to all the aforementioned research works are:

1. Gather and classify information from multiple sources (sensors, cameras, internet, historical data etc.) and extract data correlation regarding the environmental conditions and the state of the car.
2. Study dynamic decisions and estimations when some information may not be available or when the environment changes rapidly (sensor/application failure, internet connectivity error etc.).
3. Perform a study and comparison between data and model driven techniques
4. Integrate information from other vehicles. For example, vehicle-to-vehicle distance with multiple inputs will be used as indicators of traction. A key challenge in exchanging information about friction between vehicles is that the friction potential is different for each vehicle and its tires. On dry asphalt the differences could be considered small, but in adverse weather conditions the performance differences between tires grow (especially winter tires vs. summer tires).
5. Previous research works on deliberative and reflective agents have studied this field by using only theoretical analyses and empirical studies. The goal of the proposed project is to move towards real-world "smart" car application with specific requirements

INADEQUACY:

There are a number of issues that make data fusion a challenging task in the automotive domain. The majority of these issues arise from the data to be fused, imperfection and diversity of the sensor technologies, and the nature of the application environment as following:

Data imperfection: data provided by sensors is always affected by some level of impreciseness as well as uncertainty in the measurements.

Outliers and spurious data: the uncertainties in sensors arise not only from the impreciseness and noise in the measurements, but are also caused by the ambiguities and inconsistencies present in the environment, and from the inability to distinguish between them.

Conflicting data: fusion of such data can be problematic especially when the fusion system is based on evidential belief reasoning. To avoid producing counter-intuitive results, any data fusion algorithm must treat highly conflicting data with special care.

Data correlation: this issue is particularly important and common in distributed fusion settings as for example some sensor nodes are likely to be exposed to the same external noise biasing their measurements. If such data dependencies are not accounted for, the fusion algorithm, may suffer from over/under confidence in results.

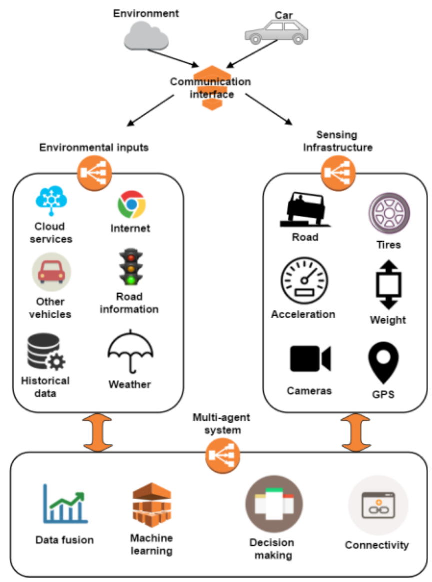
Static vs. dynamic phenomena: the phenomenon under observation may be time-invariant or varying with time. In the latter case, it may be necessary for the data fusion algorithm to incorporate a recent history of measurements into the fusion process. In particular, data freshness, i.e., how quickly data sources capture changes and update accordingly, plays a vital role in the automotive domain.

PROPOSED SOLUTION:

In this project, we couple the concept of multi-agent systems with data fusion techniques in order to develop a distributed adaptive and reliable decision making system for automotive applications.

The advantages of a multi-agent system in a smart car are many-fold. Having multiple agents, it speeds up the car's operations by providing a method for parallel computation. Inputs from sensors and car diagnostics are performed faster. Reliability and robustness are a benefit too. Car control and services are sufficiently shared among different agents. Thus, the system can tolerate failures by one or more of the agents. However, the most important thing offered by agents is connectivity. The increased connectivity offered by autonomous intelligent agents provide more sources of information. For example additionally to the on-vehicle sensors, cars can utilize information from the internet, GPS, cloud services and other vehicles. In this project we propose an MSDF methodology for processing multi-sensor data from different types of sensors and information inputs. Specifically, the proposed methodology will:

1. Collect data and inputs from on-vehicle sensors and environmental sources. Based on this input the project will provide information regarding the data correlation, it will perform data clustering and estimations. The employed use case is the estimation of friction coefficient.
2. Merge direct estimations with information from multiple on vehicle sensors as well as environmental information (other cars, internet) and employ efficient data fusion techniques.
3. Explore and address static and dynamic changes both on the vehicle and the environment. Specifically, the project will explore how these changes affect the decisions and the state of the smart car when some information is not available or when the environment changes rapidly (sensor/application failure, internet connectivity error etc.).
4. Explore adaptive learning (historical data) methodologies and compare data and model driven techniques.



Furthermore, the project will use the multi-agent system as the basis for co-operative vehicle-to-vehicle communication enhancing the accuracy and the exchange information between cars. The co-operative approach for improving traffic safety is based on communicating information and measurements between road users and also from and to other cars. The car's own measurements will be supported by the communicated data, thus helping to disseminate warnings and traffic information, and bring situational awareness. However, as aforementioned, a key challenge in using friction, or general information, in vehicle-to-vehicle is that the friction potential is different for each vehicle and the information that it is sent may not be accurate for other cars. For that reason, the project will address this issue by employing data clustering techniques using information about tires, weather and position.

Another challenge is the high variance of friction even over short stretches of road. Actually, the coefficient of friction varies a lot even for small distances. However, continuous monitoring and information exchanging is not the solution as it will flood other vehicles with information that in many cases it is not even useful. Thus, when designing a data fusion methodology, it is important to determine how sophisticated the sensors and the agents' decision will be. To improve agent sensing and overall car performance, the project will employ reflective and deliberative information gathering by intelligent agent. By being deliberative, an agent intentionally and selectively chooses how to gather information. By being reflective, an agent self-evaluates its informational needs and performance in order to understand its needs and past sensing outcomes to best guide deliberative information gathering, as well as adapt and learn as it faces new decisions in an uncertain environment. Specifically, the proposed project will implement and evaluate Partially Observable Markov Decision Processes (POMDP) for reasoning under uncertainty. Previous research works have studied this field by using only theoretical analyses and empirical studies. The goal of the proposed project is to move towards real-world "smart" car application with specific requirements.

<u>NOVELTY:</u>

The innovative aspects of the project are many-fold:

1. Multi-sensor data fusion techniques will explore static and dynamic changes both on the vehicle and the environment. Specifically, the project will explore how these changes affect the decisions and the state of the smart car when some information is not available or when the environment changes rapidly (sensor/application failure, internet connectivity error etc.).
1. Employ reflective and deliberative information gathering. By being deliberative, an agent intentionally and selectively chooses how to gather information. By being reflective, an agent self-evaluates its informational needs and performance in order to understand its needs. Previous research works on deliberative and reflective agents have studied this field by using only theoretical analyses and empirical studies. The goal of the proposed project is to move towards real-world "smart" car application with specific requirements

2. The estimation of friction coefficient will be used as a use case. Specifically the project will investigate how the estimation of coefficient of friction depends and varies on different information sources (sensors, vehicle-to-vehicle, information from cloud, historical data);
3. Propose an MSDF framework for fusing data from different types of sensors and inputs. Explore adaptive learning (historical data) methodologies and compare data and model driven techniques.

POTENTIAL BENEFITS TO INDUSTRY MEMBERS:

The project will focus on the integration and analysis of information from multiple sensors including static and dynamic changes both on the vehicle and the environment. On top of that, these techniques will be employed over a multi-agent system especially designed for on-vehicle communication. The benefits for the member companies will be many-fold. Firstly, new techniques for real-time data fusion will be developed, tested and evaluated. Also, the use case for the proposed project is the estimation of coefficient of friction which is considered as one of the most important factors for modern cars. Furthermore, the concept of multi-sensor data fusion on top of a multi-agent system will be evaluated. Last, improvements and new solutions for adaptive data fusion will be proposed, following the trends of a smart-car.

DELIVERABLES:

The proposed project deliverables will be as follows:

1. Comprehensive report on the developed techniques including details about the implemented algorithms and tools. The report will also include the results regarding the selected use case.
2. A simulation demo with a lot of different scenarios that cover a great variety of results from the selected use case.

TIMELINE / MILESTONES (PER QUARTER):

- Q1: Review of data fusion method and extraction of friction models.
- Q2: Design and implementation of the data fusion techniques targeting coefficient of friction.
- Q3: Evaluation of estimator performance in simulations.
- Q4: Evaluation of the estimator performance with experimental data

TECHNOLOGY TRANSFER:

Technology transfer will be performed in the form of comprehensive reports regarding the developed data fusion techniques.

BUDGET:

The requested budget is $50,000. The budget will cover travel expenses for meetings, acquisition of necessary equipment and salaries (PI and participating graduate students under the supervision of the PI).

REFERENCES:

[1] F. Holzmann, et al., "Predictive estimation of the road-tire friction coefficient," in IEEE *International Conference on Control Applications*, Munich, Germany, 2006, pp. 885-890.
[2] Y. Sato, *et al.*, "Study on recognition method for road friction condition," *JSAE Transaction*, vol. 38, pp. 51-56, 2007.
[3] M. Yamada, *et al.*, "Road surface condition detection technique based on image taken by camera attached to vehicle rearview mirror," *Review of Automotive Engineering*, vol. 26, pp. 163-168, 2005.
[4] A. Tuononen, "On-board estimation of dynamic tyre forces from optically measured tyre carcass deflections," *International Journal of Heavy Vehicle Systems*, vol. 16, pp. 362-378, 2009.
[5] A. Tuononen, "Vehicle lateral state estimation based on measured tyre forces," in *International Symposium on Dynamics of Vehicles on Roads and Tracks*, Stockholm, Sweden, 2009

[6] T. Kim, J. Lee and K. Yi, "Enhanced maximum tire-road friction coefficient estimation based advanced emergency braking algorithm," *2015 IEEE Intelligent Vehicles Symposium (IV)*, Seoul, 2015, pp. 883-888.

[7] M. Ito, *et al.*, "Estimation of road surface conditions using wheel speed behavior," in *International Symposium on Advanced Vehicle Control*, Tsukuba, Japan, 1994, pp. 533-538.

[8] F. Gustafsson, "Monitoring tire-road friction using the wheel slip," *IEEE Control Systems Magazine*, vol. 18, pp. 42-49, 1998.

[9] T. Umeno, *et al.*, "Estimation of tire-road friction using tire vibration model," presented at the SAE 2002, Detroit, Michigan, USA, 2002.

[10] J.-O. Hahn, *et al.*, "GPS-based real-time identification of tire-road friction coefficient," *IEEE Transactions on Control Systems Technology*, vol. 10, pp. 331-343, 2002.

[11] C. Sierra, *et al.*, "Cornering stiffness estimation based on vehicle lateral dynamics," *Vehicle System Dynamics*, vol. 44, pp. 24 - 38, 2006

[12] Prusa, Joseph M., et al. "Conceptual and Scaling Evaluation of Vehicle Traffic Thermal Effects on Snow/Ice-Covered Roads*." Journal of Applied Meteorology 41.12 (2002): 1225-1240.

BIOGRAPHICAL SKETCH

Iraklis Anagnostopoulos

Electrical and Computer Engineering Department

Southern Illinois University, Carbondale

1230 Lincoln Drive Mail Code 6603, Carbondale, IL 62901

TEL: (618) 453-7034

EML: iraklis.anagno@siu.edu

Professional Preparation:

- National Technical University of Athens, Greece, Athens, Greece
  Electrical Engineering B.S. 2008
- National Technical University of Athens, Greece, Athens, Greece
  Electrical Engineering Ph.D. 2014

Appointments:

- Assistant Professor, ECE Department of Southern Illinois University, Carbondale, 2015-present
- Post-doc, ECE Department of National Technical University of Athens, 2014-2015
- Graduate Research Assistant, ECE Department of National Technical University of Athens, 2008-2014

Publications Most Closely Related to the Proposed Project:

- I. Anagnostopoulos, J.M. Chabloz, I. Koutras, A. Bartzas, A. Hemani, D. Soudris, "Power-aware Dynamic Memory Management on May-core Platforms utilizing DVFS," *ACM Transactions on Embedded Computing Systems*, vol.13, no.1, pp.40:1–40:25, November 2013.
- K. Gyftakis, I. Anagnostopoulos, D. Soudris and D. Reisis, "A MapReduce framework implementation for Network-on-Chip platforms", *21st IEEE International Conference on Electronics, Circuits, and Systems*, Marseille France, December 2014.
- I. Anagnostopoulos, V. Tsoutsouras, A. Bartzas, D. Soudris, "Distributed run-time resource management for malleable applications on many-core platforms," *in Proceedings of DAC conference* 2013.
- I. Anagnostopoulos, A. Bartzas, G. Kathareios, D. Soudris, "A Divide and Conquer based Distributed Run-time Mapping Methodology for Many-Core platforms," *in Proceedings of DATE conference* 2012.

Other Significant Publications:

- B. Candaele, D. Soudris, I. Anagnostopoulos, "Trusted Computing for Embedded Systems," *ISBN 978-3-319-09420-5, Springer*, 2014.
- I. Anagnostopoulos, A. Bartzas, I. Filippopoulos, D. Soudris, "High-level Customization Methodology for Application-Specific NoC Architectures," *Springer Design Automation for Embedded Systems*, vol.16, no.4, pp.339-361, 2013, doi: 10.1007/s10617-013-9114-5.
- I. Anagnostopoulos, S. Xydis, A. Bartzas, Z. Lu, D. Soudris, A. Jantsch, "Custom Microcoded Dynamic Memory Management for Distributed On-Chip Memory Organizations," *IEEE Embedded System Letters*, 2011.

- A. Bartzas, P. Bellasi, I. Anagnostopoulos, C. Silvano, W. Fornaciari, D. Soudris, D. Melpignano, C. Ykman-Couvreur, “Runtime Resource Management Techniques for Many-core Architectures: The 2PARMA Approach,” in *Proceedings of the International Conference on Engineering of Reconfigurable Systems and Algorithms (ERSA*), 2011.
- S. Xydis, A. Bartzas, I. Anagnostopoulos, D. Soudris, K. Pekmestzi, “Custom Multi-Threaded Dynamic Memory Management for Multiprocessor System-on-Chip Platforms,” *in Proceedings of International Conference on Embedded Computer Systems: Architectures, Modeling, and Simulation (SAMOS)* 2010.

Synergistic Activities:

- Director of Embedded Systems Software lab in SIUC
- Program Committee: SAMOS conference 2015, GLSVLSI conference 2016
- HiPEAC Paper Award: Design Automation Conference, Austin, Texas, 2013
- Reviewer of IEEE Trans. On Computers, IEEE Micro, ACM Trans. On Embedded Systems, Journal of Low Power Electronics, Journal of Circuits, Systems and Computers, Elsevier Microprocessors and Microsystems

Collaborators and Other Affiliations:

- **Collaborators and Co-Editors:** Alexandros Bartzas (National Technical University of Athens, Greece), Bernard Candaele (Thales Group, France), Jean-Michel Chabloz (Royal Institute of Technology, Sweden), George Economakos (National Technical University of Athens, Greece), William Fornaciari (Polytechnic University of Milan, Italy), Ahmed Hemani (Royal Institute of Technology, Sweden), Axel Jantsch (Royal Institute of Technology, Sweden), Zhonghai Lu (Royal Institute of Technology, Sweden), Kiamal Pekmestzi (National Technical University of Athens, Greece), Dionysios Reisis (University of Athens, Greece), Chistina Silvano (Polytechnic University of Milan, Italy), Kostas Siozios (National Technical University of Athens, Greece), Dimitrios Soudris (National Technical University of Athens, Greece), Vasileios Tsoutsouras (National Technical University of Athens, Greece), Sotirios Xydis (National Technical University of Athens, Greece)
- **Thesis Advisor and Postgraduate-Scholar Sponsor:** Michael Weber, Setareh Behroozi, Giannis Galanis all at Southern Illinois University Carbondale

I/UCRC Executive Summary - Project Synopsis	Date:
Project Title: Environmental information and multi-sensor data fusion based performance estimations for smart cars	
Center/Site: Center for Embedded Systems/Southern Illinois University Carbondale	
Principle Investigator: Iraklis Anagnostopoulos	**Type: (New or Continuing)** New
Tracking No.: (CES office to input) **Phone :** (618) 453-7034	**E-mail :** iraklis.anagno@siu.edu
	Proposed Budget: $50,000

Abstract: The rapid growth of on-vehicle multi-sensor inputs along with off-vehicle data streams provides an opportunity for innovation in real-time decision making. The development of new advanced sensors is not sufficient enough without the utilization of enhanced signal processing techniques. Multi-sensor data fusion (MSDF) is the process of combining or integrating measured or preprocessed data originating from different active or passive sensors. Thus, data fusion strategies are of remarkable importance for the availability and robustness of the overall system. As vehicles become autonomous with personal data platform concepts such as intelligent agents and hypervisors are critical for a robust foundation. A lean design becomes the spring-board for introducing future connectivity and mobility features in a scalable manner. In this project, we aim to develop and explore data fusion techniques for decision making for automotive applications. Specifically we will combine the benefits offered by car's increased connectivity (e.g. internet, cloud services) with on-vehicle sensor information for providing detailed information about the state of the car and the environment.

Problem: In modern cars, data provided by sensors and agents is always affected by some level of impreciseness as well as uncertainty in the measurements and in many cases this information can also be controversial. Also, as the number of information sources increases the amount of data to be processed increases as well. For that reason, data fusion strategies are of remarkable importance for the availability and robustness of the overall system. With the increasing number of information sources available in today's cars, estimation of friction coefficient is a challenge. Besides using only on-vehicle information, the car can also utilize information obtained by different sources (e.g. other vehicles, internet).

Rationale / Approach: In this project, we couple the concept of multi-agent systems with data fusion techniques in order to develop a distributed adaptive and reliable decision making system for automotive applications. This project will focus on multi-sensor data fusion techniques over a multi-agent system that has been designed to provide service flexibility for modern cars. The most important thing offered by agents is connectivity. The increased connectivity offered by autonomous intelligent agents provide more sources of information. In this project we propose an MSDF methodology for processing multi-sensor data from different types of sensors and information inputs. Specifically, the proposed methodology will: (i) Collect data and inputs from on-vehicle sensors and environmental sources; (ii) Merge direct estimations with information from multiple on vehicle sensors as well as environmental information; (iii) Explore and address static and dynamic changes both on the vehicle and the environment.; and (iv) Explore adaptive learning (historical data) methodologies and compare data and model driven techniques.

Novelty: The innovative aspects of the project are many-fold: (i) Multi-sensor data fusion techniques will explore static and dynamic changes both on the vehicle and the environment; (ii) Employ reflective and deliberative information gathering; (iii) The estimation of friction coefficient will be used as a use case. Specifically the project will investigate how the estimation of coefficient of friction depends and varies on different information sources (sensors, vehicle-to-vehicle, information from cloud, historical data); and (iv) Propose an MSDF framework for fusing data from different types of sensors and inputs. Explore adaptive learning methodologies and compare data and model driven techniques.

Potential Member Company Benefits: The project will focus on the integration and analysis of information from multiple sensors including static and dynamic changes (vehicle and the environment). These techniques will be employed over a multi-agent system especially designed for on-vehicle communication. The benefits are: (i) new techniques for real-time data fusion will be developed, tested and evaluated; (ii) The use case for the proposed project is the estimation of coefficient of friction; (iii) The concept of multi-sensor data fusion on top of a multi-agent system will be evaluated.

Deliverables for the proposed year: (i) Comprehensive report on the developed techniques including details about the implemented algorithms and tools. The report will also include the results regarding the selected use case. (ii) A simulation demo with a lot of different scenarios that cover a great variety of results from the selected use case.

Milestones for the proposed year: Q1: Review of data fusion method and extraction of friction models. Q2: Design and implementation of the data fusion techniques targeting coefficient of friction. Q3: Evaluation of estimator performance in simulations. Q4: Evaluation of the estimator performance with experimental data

Progress to Date: **THIS SECTION TO BE UPDATED IN JANUARY**

Estimated Start Date: 08/01/2016	**Estimated Knowledge Transfer Date**: 08/31/2016