DECLARATION OF DR. DAVID M. BEVLY

I, Dr. David M. Bevly, declare as follows:

1. I have been retained by Volkswagen Group of America, Inc. in connection with its petition for *inter partes* review of U.S. Patent No. 5,714,927 ("the '927 patent"). I have over 10 years of experience in fields relevant to the '927 patent, including signal processing for vehicle sensor systems, vehicle radar systems, and object sensing systems. I hold a B.Sc. degree in Mechanical Engineering from Texas A&M University, a M.Sc. degree in Mechanical Engineering from Massachusetts Institute of Technology, and a Ph.D. degree in Mechanical Engineering from Stanford University. My qualifications are further set forth in my *curriculum vitae* (Exhibit A).

2. I have reviewed the '927 patent, as well as its prosecution history. I have also reviewed U.S. Patent No. 5,521,579 ("Bernhard"), U.S. Patent No. 5,325,096 ("Pakett"), and U.S. Patent No. 4,053,026 ("Fujiki").

The '927 Patent

3. The '927 patent describes methods of controlling alarm or alert indicators in automotive radar systems. The '927 patent, col. 1, ll. 7–10. According to the '927 patent, vehicle near object detection systems using radar suffer from variations in target discrimination and the reflectivity of target vehicles, which can lead to false alarms, alert dropout, and alert signal flicker. The '927 patent, col. 1, l. 13–col. 2, l. 6. The '927 patent considers these problems to relate to the "zone of coverage response

of side detection radar," and seeks to improve the zone of coverage by delaying a signal turn-off, or applying a longer sustain time to hold the signal on. The '927 patent, col. 2, ll. 10–34. For example, according to the '927 patent, sustaining an alert signal for a sustain time "improves the zone of coverage as perceived by the vehicle driver." The '927 patent, col. 2, ll. 15–34; col. 4, ll. 8–21.

4. The radar system described by the '927 patent includes side detection system 16, which has side detection radar antenna 14 and signal processor 18. The detection system detects an object in the adjoining lane, and alerts the driver when an object is detected. The '927 patent, col. 2, l. 66–col. 3, l. 27. The signal processor 18 discerns valid targets using various information such as the relative speed of the vehicle and the target, and the range rate of the target, and ignores those targets of little interest to the driver. The '927 patent, col. 3, ll. 27–51.

5. Figures 3a–3d illustrate the reflected radar signal strength, to show how weak return signals cause gaps in the alert command. To remove these gaps, the '927 patent describes "judiciously sustaining" the alert signals, "thereby extending the zone of coverage as perceived by the driver." The '927 patent, col. 3, l. 52–col. 4, l. 7. The alert signals fill in any gaps in the signal, and further add a period 48 to the end of the alert signal. As shown in Figure 4, the extended period 48 results in zone extensions 56 and 64, so that the driver "has greater assurance that the blind spot is free of an object." The '927 patent, col. 4, ll. 8–21.

FIG - 3a

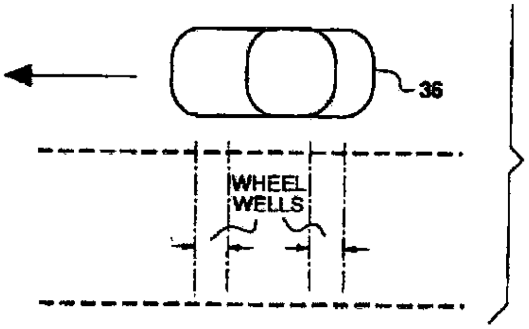


FIG - 3b

FIG - 3c

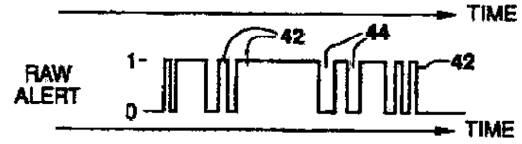


FIG - 3d

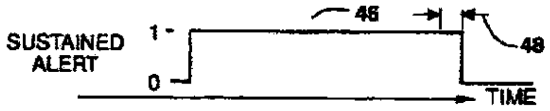
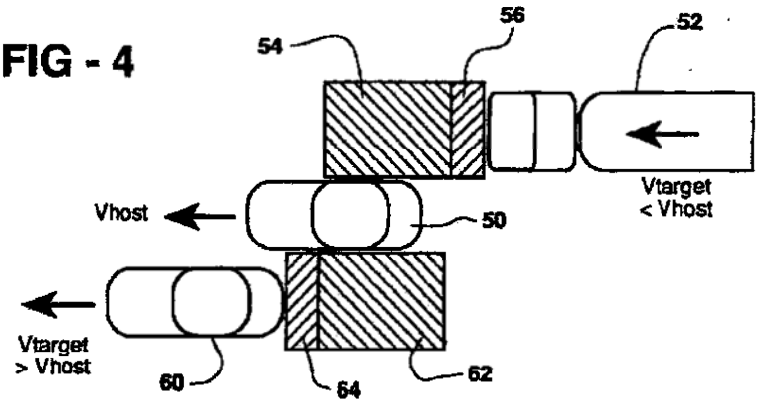


FIG - 4



6. Sustaining the alert signal follows the algorithm outlined at column 4, lines 22 to 49. Specifically, if the alert is active for at least a threshold time, a variable sustain time, selected as a function of vehicle speed, delays the turn-off of the alert. The '927 patent, col. 4, ll. 41–44.

7. In a Notice of Allowance dated July 22, 1997, the Examiner acknowledged the pertinence of several prior art documents, including Bernhard, to the method claimed

in the '927 patent, stating, for example, that "Bernhard discloses a method for providing guiding assistance for a vehicle in changing lane," but stating that

> The prior art cited herein fails to disclose a method of improving the perceived zone of coverage response of automotive radar comprising the steps of selecting a variable sustain time as a function of relative vehicle speed, and sustaining an alert signal for the variable sustain time if the alert signal was active for a threshold time.

8. Therefore, according to my understanding of the prosecution history of the '927 patent, it was allowed because it claims "selecting a variable sustain time as a function of relative vehicle speed;" and "if the alert signal was active for the threshold time, sustaining the alert signal for the variable sustain time."

The Combination of Bernhard, Pakett, and Fujiki – Claims 1, 2, and 6

9. Bernhard describes a computer-assisted guidance system for a motor vehicle that includes a number of radar devices including a rear-mounted radar device HR, a distance radar device AR , a blind spot radar device TWR, and forward-directed radar device VR. Bernhard, col. 3, ll. 34–40. "These devices detect the presence of objects in the respective area covered by them, and also permit the distance from the object to be determined." Bernhard, col. 3, ll. 40–43.

10. As described by Bernhard, radar devices measure the relative speed of objects 1 to 4, compared to the driver's vehicle 0. The driver's vehicle speed v0 is measured by

a speedometer. Bernhard, col. 4, ll. 35–40. Therefore, Bernhard describes determining the relative speed of host and target vehicles.

11. Referring to the radar devices, Bernhard states that "[t]hese devices detect the presence of objects in the respective area covered by them, and also permit the distance from the object to be determined." Bernhard, col. 3, ll. 40–43. The raw data from these radar devices are processed, including filtering out faults, and tested for sufficient plausibility. Bernhard, col. 4, ll. 40–44. Bernhard therefore detects the presence of a target vehicle, and produces an alert command.

12. The distances s01 to s04, as detected by the radar devices, are used to determine whether a lane change is possible. If a lane change is not possible, an instruction to stay in lane is issued to the driver. Bernhard, col. 5, l. 44–col. 6, l. 22. Therefore, Bernhard describes activating an alert signal in response to the alert command.

13. Pakett describes a smart blind spot detection system. Using radar, the blind spot system detects the presence of an obstacle, measures the relative speed between the vehicle and the obstacle indicated by the Doppler shift in the radar signals, and generates an alarm if the obstacle is traveling at a similar speed and direction as the vehicle. Pakett, col. 2, ll. 8–13. To prevent unnecessary alarms, the smart blind spot system only warns the driver if the object persists for the "persistence period," which is the time it takes for the vehicle to travel 15 feet, or if the presence of an object is indicated within two seconds of the previous warning. Pakett, col. 6, ll. 43–56. Then

the alarm is sustained for at least one second after the object is no longer detected. If the alarm has been on for more than one second without reactivation, the alarm is stopped. Pakett, col. 7, l. 64–col. 8, l. 5; Fig. 3A.

14. Pakett also describes a low pass filter 27, which serves to eliminate signals for objects that only briefly appear in the vehicle's blind spot, as these objects are not of interest to the driver. Pakett, col. 5, ll. 11–31. The low pass filter 27 passes signals of lower frequency, i.e., those signals that appear for longer duration. Therefore, the low pass filter 27 distinguishes signals that are maintained for at least a threshold amount of time from signals that only briefly appear. Only those signals that are greater than the threshold time are passed through the filter and to be utilized to activate an alarm signal. These signals, which are longer than the threshold time, may be sustained by the system described in Pakett, for a sustain time of one second. Pakett, col. 7, l. 31–col. 8, l. 10.

15. Therefore, in the system described by Pakett, signals that are active for a threshold time are sustained, and the zone of coverage would appear, to the driver, to increase according to the sustain time.

16. Fujiki describes a vehicle system including a radar device that emits a radar signal in order to detect obstacles relative to the vehicle. The system prevents "stop starting braking due to momentary 'safe' signals." Abstract. The system maintains a safe distance between vehicles by comparing the relative speed and distance between the vehicles to a setpoint curve, and applying the brake when the vehicles are within

the safe distance for the measured relative speed. Fujiki, col. 2, ll. 7–13; Fig. 3B. If the system determines that braking is not required to maintain a safe distance between the vehicles, the system checks whether the brake was just previously on. Fujiki, col. 5, ll. 46–57. If the brake was just previously on, the system applies additional braking, i.e., sustains the brake, for a period of time. Fujiki, col. 5, ll. 59–61.

17. Fujiki describes three preferable periods of time that the brake will be sustained: t_1, t_2, or t_3. One of these time periods, t_3, is expressly described as a function of the relative velocity of the vehicles. Fujiki, col. 5, ll. 59–67 ("t_3 is a function of the pre-selected distance D and the relative velocity dR/dt just prior [sic] the danger signal disappearing, for which the additional braking will take place."). Fujiki therefore describes selecting a variable sustain time as a function of relative vehicle speed.

18. The purpose of this system, according to Fujiki, is to sustain the braking system in an activated state for a predetermined distance after a danger signal disappears. Fujiki, col. 1, ll. 53–58. Thus, Fujiki is improving the perceived zone of coverage of the detection system (after the signal has been persistent for a threshold time).

19. Regarding claim 2 of the '927 patent, as described above, the variable sustain time of Fujiki is a function of the relative vehicle speed. Fujiki, col. 5, ll. 59–67. Fujiki states that the sustain time is a function of a predetermined distance and the relative velocity. This time must be the product of the distance and the inverse of the relative velocity. Therefore, Fujiki describes that the sustain time is an inverse function of the relative vehicle speed.

20. Regarding claim 6 of the '927 patent, as stated above, Bernhard, Pakett, and Fujiki each describe determining the host vehicle speed. Bernhard, col. 4, ll. 35–40; Pakett, col. 7, ll. 31–32; Fujiki, col. 2, ll. 28–31. As further described above, Pakett includes a persistence period of the time it would take for the vehicle to travel 15 feet. Pakett, col. 6, ll. 43–46, col. 7, ll. 32–36. The determined time, i.e. the threshold time, is a function of vehicle speed, as the speed of the vehicle will dictate how long it will take the vehicle to travel 15 feet.

I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code.

Dated: March 26, 2015 David Bevly

Dr. David M. Bevly

Exhibit
A

David M. Bevly

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Department of Mechanical Engineering
Auburn University
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Current Position

Auburn University — **Auburn, AL**
Albert Smith Endowed Professorship — *2010-2015*
Professor, Department of Mechanical Engineering — *2010-Present*
Associate Professor, Department of Mechanical Engineering — *2007-2010*
Assistant Professor, Department of Mechanical Engineering — *2001-2007*
In charge of teaching mechanical engineering courses and developing a strong externally funded research program in the area of dynamics, controls, and transportation systems.

Education

Stanford University — **Stanford, CA**
Ph.D., Mechanical Engineering, September 2001. Thesis directed by Professor Bradford Parkinson entitled "High Speed, Dead Reckoning, and Towed Implement Control for Automatically Steered Farm Tractors Using GPS."
Major Area: Automatic Control, Minor Area: Mechatronic Systems

Massachusetts Institute of Technology — **Cambridge, MA**
Master of Science, Mechanical Engineering, September 1997. Thesis directed by Professor Steven Dubowsky, entitled "Action Module Planning and Cartesian Based Control of an Experimental Climbing Robot."

Texas A&M University — **College Station, TX**
Bachelor of Science, Mechanical Engineering, Summa Cum Laude, May 1995. Broad curriculum in mechanical engineering with emphasis in design, dynamics, and control. Completed undergraduate research units directed by Professor Christian Burger.

Awards

2007 SAE Ralph R. Teetor Educational Award
2005, 2008, 2010 Outstanding Mechanical Engineering Faculty Member Award
2010 Walker Teaching Award
2006 Office of Naval Research Young Investigator Award
2006 Army Research Office Young Investigator Award
2000 SAE Myers Award for Outstanding Student Paper
Best Paper of Session: ION GPS 2000
Best Presentation of Session: ACC 2000

Research Background

GPS Lab, Stanford — **Stanford, CA**
Graduate Researcher — *1998-2001*
Performed research and implementation of hardware for automated control of a farm tractor using GPS. Developed accurate vehicle models for high-speed control and towed implement control. Responsible for programming data acquisition equipment for Lynx Real Time Operating System and integration of several analog sensors. Developed method for integrating multiple inertial type sensors with GPS, through an EKF, for estimating multiple biases and dead reckoning control of the tractor. Created computer simulations and models to verify control and estimation techniques performed on the tractor.

DYNAMIC Design Lab, Stanford — **Stanford, CA**
Graduate Researcher — *1999-2001*
Initiated the ideas and performed research on the use of GPS velocity measurements for estimation of vehicle states and developed a method for measuring wheel slip and side-slip angle. Developed vehicle simulation models and performed experiments on a test vehicle to verify methodology.

Teaching Experience

Auburn University — **Auburn, AL**

MECH 4420 - Vehicle Dynamics — *2002-present*

Developed this new course as part of the College of Engineering's Automotive Certificate Program. Emphasized the importance of computational numerical methods to simulate and analyze vehicle systems. Was able to secure an Infiniti G35 test vehicle from Nissan which was instrumented by graduate students in the laboratory and used as part of the class. The students test drive the vehicle, collect data, and provide lab reports analyzing the experiments and data.

MECH 3140 - System Dynamics and Controls — *2001-present*

Have taught this traditional undergraduate course most Fall and Spring Semesters since arriving at Auburn University. Assigned homework and team design projects requiring simulation, analysis, and design of a control system using MATLAB.

MECH 7710 - Optimal Estimation and Control — *2002-present*

Developed this new graduate course. The class consists of assignments which utilize data from experimental research platforms and culminates in a team research design project.

MECH 6970 - Fundamentals of GPS — *2005-present*

Developed this new undergraduate/graduate course on the fundamentals of GPS with graduate student Matthew Lashley. The class consists of assignments which utilize data from experimental research platforms in the laboratory and the use of GPS equipment from the laboratory.

HONORS AND AWARDS

While at Auburn, Dr. Bevly has received the following awards:

1. 2011 Auburn University Graduate School Outstanding Faculty Member
2. Albert Smith Professorship, 2010-2015
3. Philpott-Westpoint Stevens Professorship, 2008-2010
4. 2010 William Walker Teaching Award
5. 2010 Auburn Alumni Engineering Council Outstanding Faculty Award
6. 2008 Auburn Alumni Engineering Council Outstanding Faculty Award
7. 2007 SAE Ralph R. Teetor Educational Award
8. 2006 Office of Naval Research Young Investigator Proposal (ONR YIP) Recipient
9. 2006 Army Research Office Young Investigator Proposal Recipient
10. 2005 Auburn Alumni Engineering Council Outstanding Faculty Award
11. 2003 Auburn Alumni Engineering Council Junior Faculty Research Award

SCHOLARLY CONTRIBUTIONS

The following section outlines Dr. Bevly's scholarly contributions and is divided into three areas: teaching, research, and outreach.

A. Teaching

1. **Courses Taught**—Table 2 indicates the courses that Dr. Bevly has taught over the past three years. Lecture/lab hours and enrollment are also noted. MECH 7990 Research and Thesis and MECH 8990 Research and Dissertation courses have been omitted.

Table 2. Actual Course Taught from Spring 2012-2015

Semester	*Course*	*Hours*	*Enrollment*
Fall 2012	MECH 3140 System Dynamics and Control	3 lec.	41
Spring 2013	MECH 4420 Vehicle Dynamics	3 lec.	20
	MECH 7710 Optimal Estimation and Control	3 lec.	12
Fall 2013	MECH 3140 System Dynamics and Control	3 lec.	60
	MECH 5970 Fundamentals of GPS	3 leg	22
Spring 2014	MECH 3140 System Dynamics and Control	3 lec.	33
	MECH 4420 Vehicle Dynamics	3 lec.	18
Fall 2014	MECH 3140 System Dynamics and Control	3 lec.	50
Spring 2015	MECH 4420 Vehicle Dynamics	3 lec.	23
	MECH 7710 Optimal Estimation and Control	3 lec.	18

2. **Graduate Students (Graduated)**

As outlined below, Dr. Bevly has served as the major professor advisor of 10 PhD students and 37 MS students. The names of the students research topic, department, degree, and graduation year are provided below.

Student	Research Topic	Dept.	MS/PhD	Year
Robert Daily	Model-free Control of Unmanned Ground Vehicles	ME	PhD	2008
Winnard Britt	A software and hardware system for the autonomous control and navigation of a trained canine	CS	PhD	2009
Matthew Lashley	Modeling and Performance Analysis of GPS Vector Tracking Algorithms	EE	PhD	2009
William Travis	Navigation Accuracy of Various Sensors for Ground Vehicles	ME	PhD	2010
Wei Huang	On-line Vehicle Estimation and Navigation	ME	PhD	2010
Jeffrey Miller	A Maximum Effort Control System for the Tracking and Control of a Guided Canine	ME	PhD	2010

David Broderick	Dynamic Gaussian Process Models for Model Predictive Control of Vehicle Roll	EE	PhD	2012
Ben Clark	Fault Detection and Exclusion in Deeply Integrated GPS/INS	ME	PhD	2012
Jeremy Dawkins	Terrain and Road Characterization and Roughness Estimation for Simulation and Control of Unmanned Ground Vehicles	ME	PhD	2011
Yan Wang	Integrated sensor fusion for vehicle control applications	ME	PhD	2014
Paul Pearson	Modeling the Variations of Tractor Dynamics for Typical Farm Applications	ME	MS	2007
William Travis	Navigation Accuracy of Various Sensors for Ground Vehicles	ME	MS	2006
John Wall	Navigation in GPS Denied Areas	ME	MS	2007
Kenny Lambert	Anti-roll Control of Tele-operated UGVs	ME	MS	2007
Dustin Edwards	Mobility Models for FCS UGVs	ME	MS	2008
Matt Lashley	Development and Analysis of Deeply Integrated GPS/INS	EE	MS	2006
Michael Newlin	Development of a Software GPS Receiver	EE	MS	2006
Josh Clanton	GPS Applications for Advanced Driver Assistance Systems	EE	MS	2006
Benton Derrick	Direct Adaptive Control of Farm Tractors	ME	MS	2008
Rusty Anderson	Using GPS for Model Based Estimation of Critical Vehicle States and Parameters	ME	MS	2004
John Plumlee	Novel Control Allocation and Quadratic Programming Algorithms for Control of Aero and Ground Vehicles	ME	MS	2004
Christopher Hamm	Comparison of GPS/INS Integration Techniques for High Dynamic Environments	EE	MS	2005
Evan Gartley	Adaptive Steering Control of Farm Tractors	ME	MS	2005
Randy Whitehead	Determination of Vehicle Parameters that Influence Vehicle Rollover Propensity	ME	MS	2005
Warren Flenniken	Low-level GPS/INS Sensor Fusion for Improved Vehicle Navigation	ME	MS	2005
David Hodo	Development of an autonomous mobile robot-trailer system for UXO detection	EE	MS	2007
Harold Henderson	Relative positioning of unmanned ground vehicles using ultrasonic sensors	ME	MS	2008
Andrew Nevin	Registration and tracking of objects with computer vision for autonomous vehicles	EE	MS	2009
Kenneth Lambert	A study of vehicle properties that influence rollover and their effect on electronics stability controllers	ME	MS	2007
Dustin Edwards	Parameter estimation techniques for determining safe vehicle speeds in UGVs	ME	MS	2008
Ben Clark	GPS/INS Operation in Shadowed Environments	ME	MS	2008
Ryan Hill	Tire Force Estimation in Off-Road Vehicles using Suspension Strain and Deflection Measurements	ME	MS	2012

Lowell Brown	Roll & Bank Estimation Using GPS/INS and Suspension Deflections	ME	MS	2012
Scott Martin	Closely Coupled GPS/INS Relative Positioning for Automated Vehicle Convoys	ME	MS	2011
Jonathan Ryan	A Fully Integrated Sensor Fusion Method Combining a Single Antenna GPS Unit with Electronic Stability Control Sensors	ME	MS	2011
Chris Rose	Robust lane detection using Vision/IMU measurements	EE	MS	2010
Jordan Britt	Lane detection and vehicle attitude using Lidar	EE	MS	2010
John Allen	Use of Vision Sensors and Lane Maps to Aid GPS-INS Navigation	ME	MS	2011
William Woodall	Low-Bandwidth Three Dimensional Mapping and Latency Reducing Model Prediction to Improve Teleoperation of Robotic Vehicles	CS	MS	2012
Mike Payne	Non-Collocated Control of an Autonomous Vehicle-Trailer System Using State Estimation	EE	MS	2012
Michael Wooten	High-Dynamic Range Collision Detection using Piezoelectric Polymer Films for Planar and Non-planar Applications	EE	MS	2013
Robert Williams	Evaluation of Beam Load Cell Use for Base Reaction Force Collision Detection on Industrial Robots	ME	MS	2014
James Salmon	Guidance of an Off-Road Tractor-Trailer System Using Model Predictive Control	ME	MS	2013
Thomas Bitner	Detection and Removal of Erroneous GPS Signals Using Angle of Arrival	ME	MS	2013
Eric Broshears	Ultra-wideband Radio Aided Carrier Phase Ambiguity Resolution in Real-Time Kinematic GPS Relative Positioning	ME	MS	2013
Jameson Colbert	Development of a Custom Data Acquisition System for the Study of Vehicle Dynamics in Longer Combination Vehicles	ME	MS	2014
Andrew Hennigar	Analysis of Record and Playback Errors of GPS Signals Caused by the USRP	ME	MS	2014

3. Graduate Students (Current)

Dr. Bevly is currently serving as the major professor advisor for 6 PhD students and 17 MS students. Listed below is each student, graduate level, department, and topic of study.

Student	Research Topic	Dept.	Degree
Scott Martin	Vector tracking aided carrier phase for GPS attitude	ME	PhD
Lowell Brown	Model parameter uncertainty and sensitivity for control performance guarantees	ME	PhD
Chris Rose	Optical flow for UGV navigation using plenoptic camera	ME	PhD
Jordan Britt	Simultaneous localization, mapping and sensor calibration	ME	PhD
Jonathan Ryan	Vehicle dynamic constraints to aid navigation	ME	PhD
David Hodo	Network based navigation	EE	PhD
Daniel Salmon	Vehicle based models and sensors to improve navigation	ME	MS

Christopher Collins	Network based direct Y acquisition	ME	MS
Sostenez Perez	Sensitivity and accuracy of friction and mass estimation in heavy vehicles	ME	MS
John Dan Pierce	Sensor fusion for pedestrian navigation	ME	MS
William Apperson	GPS guidance of a tractor implement	ME	MS
Brian Keyser	Real-time implementation of a vector tracking receiver on an FPGA	ME	MS
Sarah Preston	Use of clock bias for detecting false signals	EE	MS
Nate Carson	GPS Spoofing detection and mitigation using networked receivers	ME	MS
Robert Cofield	Map based navigation	ME	MS
Scott Smith	DRTK/Radar fusion for robust vehicle following	ME	MS
Joshua Starling	Multi-antenna signal processing for GPS	ME	MS
Gabriel Morales	Magnetometer based vehicle navigation	ME	MS
Velislav Stemenov	Lidar based terrain perception	ME	MS
Jacoby Golden	Image tracking for UAV/UGV collaboration	ME	MS
Trip Richert	GNSS Vector Tracking analysis	EE	MS
Joseph Hamilton	Multi-antenna signal processing for GPS	EE	MS
Xialong Cao	MPC control for vehicle model uncertainty in CACC systems	ME	MS

4. Committee Members

Dr. Bevly has served as a committee member or outside reader for 12 students.

1. Abby Anderson, M.S., May 2006, "Design, Testing, and Simulation of a Low-Cost, Light-Weight, Low-G, IMU for the Navigation of an Indoor Blimp."
2. Darrel Krueger, MS, December, 2007, "Investigation of Lateral Performance on and ATV Tire on Natural, Deformable Surfaces."
3. Desheng Ma, PhD, May 2010, "Design and Implementation of RF Receiver Front-end and Tunable Filter."
4. Yuan Yao, PhD, May 2010, "Design and Implementation of High-Speed Low-Power Data Converters."
5. Guangli Ma, PhD, December 2010, "Modeling, Machine Vision Sensing and Position Control of Braiding Point based on Braiding Process"
6. Robert Jantz, MS, May 2011, "Controlling the Speed of a Magnetically-Suspended Rotor with Compressed Air."
7. Russell Green, MS, August 2011, A Non-contact Method for Sensing Tire Contact Patch Deformation Using a Monocular Vision System and Speckled Image Tracking
8. Robert Jantz, MS, May 2011, "Controlling the Speed of a Magnetically-Suspended Rotor with Compressed Air."
9. James Jantz, MS, May 2014, Development of a Multi-mode Adaptive Controller and Investigation of Gain Variations with Speed and Balance Changes
10. Robert Thetford, Jr., MEE, "Visual Position and Angle Recognition using a Neural Network" August 2012.
11. Siwei Wang MEE "Design and Analysis of Trailer System for the Metalmapper Sensor", May 2013.
12. Brian Reitz, PhD, AE, Dec 2014, "Control System Development for Autonomous Aerobatic Maneuvering with a Fixed-Wing Aircraft."

5. Courses and Curricula Developed

While at Auburn, Dr. Bevly has developed three new courses, each of which is described below.

MECH 4420 Vehicle Dynamics
This course developed by Dr. Bevly as part of the Automotive Certificate in Engineering program is a three hour undergraduate technical elective. The course introduces students to the basic mechanics governing vehicle performance, analytical methods, and terminology. The students are given assignments that require the development of mathematical models in order to simulate and analyze the various components of vehicle dynamics. The class also contains an un-official lab in which the students drive instrumented test-vehicles donated to Dr. Bevly's research program in order to collect data. This provides the students additional exposure to sensors and instrumentation as well as simulation and model validation, and it is an example of Dr. Bevly's commitment to integrate his research with the undergraduate education at Auburn. The class also contains a final project in which students must present model development, simulation and experimental results to the class and answer questions from members of Dr. Bevly's research lab.

MECH 7710 Optimal Estimation and Control
This course is a graduate class in optimal control and estimation and is intended to be a follow-up class to ELEC7500. The class covers statistical modeling of disturbances and measurement noises and develops methods to design sensor fusion and estimation algorithms to account for the statistical uncertainties. The class consists of several assignments that utilize GPS and IMU data from Dr. Bevly's research projects and a final project in which students can apply the material from the class to a problem related to their area of research.

MECH 5970 Fundamentals of GPS
Developed this new undergraduate/graduate course on the fundamentals of GPS with graduate student Matthew Lashley. The class consists of assignments which utilize data from experimental research platforms in the laboratory and the use of GPS equipment from the laboratory.

6. Grants Related to Teaching - None.

7. Publications Related to Teaching - None.

8. Other Contributions to Teaching - None.

9. Statement of Teaching Philosophy and Self-evaluation

a. Philosophy—As a professor of mechanical engineering, my goal is to give students a practical yet theoretical foundation that will prepare them for jobs in industry or further work in academia. Because I believe practical examples are the best way to motivate students, I combine theory and practice by giving examples from past work and research. Test platforms used in my GPS and Vehicle Dynamics Laboratory are used to provide data, examples, and experience to students in a variety of classes taught by Dr. Bevly. This exposure allows students the opportunity to get hands-on experience applying theories taught

in classes to cutting-edge platforms. I strive to give the students I interact with, both in my research group and in the classroom, the invaluable experiences gained from building and working with experimental systems.

Along with using real-world examples to give students the basic theoretical skills to advance in engineering, I seek to create a professional atmosphere that cultivates responsibility and respect. My assignments stress the importance of self-motivation as they challenge students to extend their knowledge beyond class discussions and lecture notes. Furthermore, these assignments teach students that they are ultimately responsible for their success, a lesson that I hope students take with them outside the classroom. Another component of my classes is team projects. Not only do these projects teach students how to work together and respect each other, they also provide opportunities for professional development as students are required to present their projects before their peers. By relying on real-world examples and creating a professional environment that stimulates learning and growth, I believe my classroom prepares students to become successful engineers in the twenty-first century.

b. Self-evaluation—My level of effectiveness as a teacher can be demonstrated by my student evaluations given at the end of the semester. The final question on the survey asks students to rank the instructor's effectiveness, with 6 being the highest score Table 3 illustrates the responses from all the classes I have taught at Auburn, with the exception of MECH 6970 Special Topics: Fundamentals of GPS. The effectiveness scores of all classes result in an average score of ***5.4***, indicating that the majority of students find my teaching effective.

Table 3. Summary of Recent Student Evaluations.

Semester	*Course*	*Responses*	*Effectiveness*
Fall 2012	MECH 3140	20	5.1
Spring 2013	MECH 7710	11	5.5
	MECH 4420	7	5.7
Fall 2013	MECH 3140	31	4.9
Spring 2014	MECH 3140	18	5.2
	MECH 4420	8	5.9
Fall 2014	MECH 3140	21	5.3

B. Research/Creative Work

1. Books

1. David M. Bevly and Steward Cobb, *GNSS For Vehicle Control*, published by Artech, 2010.

2. Article-length Publications

Dr. Bevly has written 3 book chapters, 37 journal articles, 35 of which are in print and 2 of which are currently under review. Dr. Bevly also has published 3 magazine articles and 107 conference papers. Dr. Bevly's Google Scholar H-index is 26.

a. Book Chapters

1. David M. Bevly, Demoz Gebre-Egziabher, Mark Petovello, "Integration of GNSS and INS: Part 1" in *GNSS Applications and Methods,* published by Artech, 2009
2. David M. Bevly, Demoz Gebre-Egziabher, Mark Petovello, "Integration of GNSS and INS: Part 2" in *GNSS Applications and Methods,* published by Artech, 2009
3. Bevly, D. M., Gebre-Egziabher, D., and Parkinson, B. W., "Error Analysis of a Dead Reckoning Navigator for Ground Vehicle Guidance and Control," *selected to be published in the new GPS Red Book.*

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c. Articles

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90. Travis, W., Simmons, A., Bevly, D.M., "Corridor Navigation with a Lidar-INS Kalman Filter Solution," *Proceedings of the 2005 IEEE Intelligent Vehicles Conference*, Las Vegas, NV, June 6-8, 2005, pp. 343-348.
91. Anderson, R., Bevly, D.M., "Estimation of Tire Cornering Stiffness Using GPS to Improve Model Based Estimation of Vehicle States," *Proceedings of the 2005 IEEE Intelligent Vehicles Conference*, Las Vegas, NV, June 6-8, 2005, pp. 801-806.
92. Hamm, C., Flenniken, W., Bevly, D.M., Lawrence, D., "Comparative Performance Analysis of Aided Carrier Tracking Loop Algorithms in High Noise/High Dynamic Environments," *Proceedings of the 2004 ION-GNSS Conference*, September 12-24, 2004.

93. Anderson, R., Bevly, D.M., "Estimation of Vehicle Slip Angle using GPS/INS Measurements with a Model Based Estimator," *Proceedings of the 2004 American Control Conference*, Boston, MA, June 2004, pp. 2122 – 2127.
94. Plumlee, J., Bevly, D.M., and Hodel, S., "Control of a Ground Vehicle using Quadratic Programming Based Control Allocation," *Proceedings of the 2004 American Control Conference*, Boston, MA, June 2004, pp. 4704 – 4709.
95. Travis, Whitehead, Bevly, and Flowers, "Using Scaled Vehicles to Investigate the Influence of Various Properties on Rollover Propensity," *Proceedings of the 2004 American Control Conference*, Boston, MA, June 2004, pp. 3381-3386.
96. Whitehead, Travis, Bevly, and Flowers, "A Study of the Effect of Various Vehicle Parameters on Rollover Propensity," *Proceedings of the 2004 SAE Automotive Dynamics Stability & Controls Conference*, SAE Paper No. 2004-01-2094, Detroit, MI, May 2004.
97. R. Behringer, B. Gregory, V. Sundareswaran, B. Addison, R. Elsley, W.Guthmiller, J. deMarchi, R. Daily, D. Bevly, C. Reinhart. Development of an Autonomous Road Vehicle for the DARPA Grand Challenge. IFAC Symposium on Intelligent Autonomous Vehicles 2004, Lisbon, July 5-7, 2004.
98. Behringer, V. Sundareswaran, B. Gregory, R. Elsley, B. Addison, W. Guthmiller, R. Daily, D. Bevly. The DARPA Grand Challenge "Development of an Autonomous Vehicle. IEEE Symposium on Intelligent Vehicles 2004, Parma, June 14-17, 2004.
99. Van der Loos, Kautz, Schwandt, Anderson, Chen, and Bevly, "A Split-Crank, Servomotor-Controlled Bicycle Ergometer Design for Studies in Human Biomechanics," *Proceedings of the 2002 IEEE/RSJ Conference on Intelligent Robotics and Systems*, October 2002, pp. 1409-1414.
100. Bevly, D. M., Ryu, J., Sheridan, R., Gerdes, J. C, "Integrating INS Sensors with GPS Velocity Measurements for Continuous Estimation of Vehicle Sideslip and Tire Cornering Stiffness," *Proceedings of the 2001 American Controls Conference*, June 2001, Arlington, VA.
101. Bevly, D. M., Rekow, A., Parkinson, B., "Evaluation of a Blended Dead-Reckoning and Carrier Phase Differential GPS System for control of an Off-Road Vehicle," *Proceedings of the 1999 ION-GPS Meeting*, Nashville, TN, September 1999
102. Bevly, D.M., Parkinson, B.W., "Carrier-Phase Differential GPS for Control of a Tractor Towed Implement," *Proceedings of the 2000 ION-GPS Meeting*, Salt Lake City, Utah, September 2000 (best paper of session award).
103. Bevly, D.M., Rekow, A., Parkinson, B., "Incorporating INS with Carrier-Phase Differential GPS for Automatic Steering Control of a Farm Tractor," Presented at the 1999 SAE Intl. Off-Highway and Powerplant Congress & Exposition, Indianapolis, IN, September 1999, Reprinted in *Agricultural Machinery, Tires, Tracks, and Traction (SP-1472)*, Paper No. 1999-01-2851 (received the 2000 SAE Myers Award for Outstanding Student Paper).
104. Bevly, D. M., Farritor, S., Dubowsky, S., "Action Module Planning and its Application to an Experimental Climbing Robot," *Proceedings of the IEEE International Conference on Robotics and Automation*, Sept. 2000, San Francisco, CA.
105. Bevly, D. M., Rekow, A., Parkinson, B., "Comparison of an INS vs. Carrier Phase DGPS Attitude in the Control of Off-Road Vehicles," Proceedings of the 1999 ION Annual Meeting, Cambridge, MA, June 1999.
106. Bevly, D. M., et. al., "The Use of GPS Based Velocity Measurements for Improved Vehicle State Estimation," *Proceedings of the 2000 American Control Conference*, June 2000, Chicago, IL.

107. Bevly, D. M., Gerdes, J. C., Parkinson, B., "Yaw Dynamic Modeling for Improved High Speed Control of a Farm Tractor," *Proceedings of the 2000 ASME IMECE*, Orlando, FL.

3. Papers or Lectures - All are invited talks.

1. "GPS and Sensor Fusion for ITS Applications," Auburn University ITE Student Chapter Meeting, 10/9/14.
2. "Ground Vehicle Navigation in 20 Years," Panel on Navigation 2034 at ION GNSS 2014, 9/11/14
3. "Enhancing Society Through Automation & Intelligent Transportation Systems (ITS)," Panel Speaker at SxSW, March 2014.
4. "GPS and its use for Vehicle Navigation and Control Systems," Chalmers University, Gothenburg, Sweden, May 23, 2013.
5. "Sensor Fusion for Navigation and Control of Ground Vehicles," Presented at Draper Laboratories' 5th Annual Autonomous Guidance, Navigation, and Control Symposium, 5/16/13
6. "Integration of IMUs with External Signals: Overview and Examples," DARPA Ultimate Navigation Chip (uNavChip) Workshop, 4/9/13.
7. "GPS/INS Sensor Fusion for Navigation and Vehicle Control," Workshop on Navigation, Perception, Accurate Positioning and Mapping for Intelligent Vehicles at the 2012 IEEE Intelligent Vehicle Symposium, Alcalá de Henares, Spain, 5/3/2012.
8. "GPS and its use for Vehicle Navigation and Control Systems," University of Minnesota, 12/7/11.
9. GPS and its use for Vehicle Navigation and Control Systems," University of California-Riverside Colloquium Speaker, 11/21/11
10. "Sensor Fusion for Navigation in Degraded Environments," Stanford's 2nd Annual PNT Symposium, 11/17/11.
11. "GPS and its use for Vehicle Navigation and Control Systems, Clemson University International Center for Automotive Research (CU-ICAR), 10/25/11.
12. "The Global Positioning System and its Use for Control of Vehicles," University Pierre and Marie Curie, France, 9/1/10.
13. CN473: Autonomous Land Navigation using GPS/INS, GNSS Solutions Tutorial, given at the ION-GNSS in Portland, OR, September 20, 2010.
14. Modeling and System Identification of Farm Tractors," One day workshop presented to John Deere, 7/29/10.
15. "IMU Errors and Their Effect on Navigation Performance," DARPA workshop on Primary and Secondary Calibration on Active Layers, 6/22/10.
16. "GPS for Navigation and Control of Highway Vehicles," presented to Ford Research Group, 4/22/2009.

17. CN473: Autonomous Land Navigation using GPS/INS, GNSS Solutions Tutorial, given at the ION-GNSS in Savannah, GA, September, 2008.
18. Auburn University's GPS Vehicle Dynamics Research and Application to the DARPA Grand Challenge," presented to General Motors, 4/13/07
19. "GPS/INS Vehicle Modeling, Navigation, and Control," Army Research Office Workshop on Mobility and Control in Challenging Environments Olin College, Needham, MA, Oct 5-6, 2006.
20. "The Global Positioning System and its Use for Modeling Various Platforms," Texas A&M University's Mechanical Engineering Graduate Seminar Series, 9/22/06.
21. "Navigation for Control of Ground Vehicles," Half-day workshop given to engineers at Redstone Technical Test Center.
22. "Navigation for Control of Ground Vehicles," Half-day workshop at the 2006 Intelligent Vehicle Symposium.
23. "The Use of GPS in Vehicle Control and Navigation," presented to GM R&D Technical Center, 2/15/06
24. "Overview of Auburn University's Vehicle Dynamics Research," Ford Research Center Seminar, 4/15/05
25. "Auburn University's Participation in the DARPA Grand Challenge" presented at Texas A&M University, 10/22/2004.
26. "The Global Positioning System and its use for Control of Ground Vehicles" presented at the University of Houston, 10/21/2004.
27. "The Global Positioning System and its use for Control of Ground Vehicles" presented at Rice University, 10/20/2004.
28. "The Global Positioning System and its use for Control of Agricultural Vehicles" presented at the University of Nebraska, 4/1/2004.
29. "The Global Positioning System and its use for Estimation and Control of Vehicles" presented at the AUVSI Pathfinder Chapter Symposium, 4/3/2003.
30. "GPS and Its Use in Transportation and Automotive Applications" presented at the Alabama Section of the Institute of Transportation Engineers.

4. Exhibitions

1. Whitehead, R., Clark, B., Breland, M., Lambert, K., Bevly D.M., "Scale Vehicle Electronic Stability Control," *ESV International Collegiate Student Safety Technology Design Competition*, Washington D.C., June 6-9, 2005. (One of only two teams to represent North America)

5. Performances - None.

6. Patents and Inventions

1. GPS Control of a Tractor Towed Implement (Patent No. US 6,434,462).
2. Determination and Control of Vehicle Sideslip Using GPS (Patent No. US 6,681,180).

3. Method and Apparatus for Vehicle Control, Navigation, and Positioning (Patent No. US 6,732,024).

7. **Other Research/Creative Contributions** - None.

8. **Proposals and Grants**

Dr. Bevly has secured over $15 million dollars in extramurally funded research as a PI or Co-PI (over $13M as PI and over $6M of which is current), including two Young Investigator Proposal awards. The funded proposals are listed below (note that proposals not funded are not shown).

Externally Funded Proposals

1. Bevly (PI/PD), "Low-cost Ground Vehicle Navigation System," CERDEC, $300K, 3/1/2015-4/30/2016.
2. Bevly (PI/PD), "Development of a LIDAR Evaluation Software Tool," NASA MSFC, $50K, 3/1/2015-8/31/2015.
3. Bevly (PI/PD), "Evaluation of Vehicle Navigations Systems," TARDEC, $30K, 3/1/2015-8/31/2015.
4. Bevly (PI/PD), Lim, A., "NetAssure: Network-Based Navigational Assurance," IS4S, $416K, 9/1/2014-8/31/2016.
5. Bevly (PI/PD), "Continued GPS radio frequency signal recorder development," US Army AMRDEC (through Gleason), $57K, 10/1/2014-6/30/2015
6. Bevly (PI/PD), "Vehicle Fuel Consumption Modelling," Vecterra Technologies, $3K, 6/9/14 – 12/15/14.
7. Bevly (PI/PD), "Lidar Scanning Test," NASA MSFC, $3K, 8/4/14 – 8/29/14
8. Bevly (PI/PD), "GPS and DRTK Support for DSAT Vehicles," US Army TARDEC (through DCS), $100K, 8/1/2014-10/30/2014
9. Bevly (PI/PD), "GPS Study & Report," Defense Contractor, $1.25M, 6/14/14-6/13/19.
10. Bevly (PI/PD), Murray (Co-PI), Turochy, "Lane Change/Merge Fundamental Research: Phase 1," $304K, 10/1/2014-12/31/2015.
11. Bevly (PI/PD) "Introductory Analysis of Magnetometers," Parson, $125K, 3/2014-8/30/15.
12. Bevly (PI/PD), Murray, Turochy, Sesek, Shelton, Lim, "Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing & Stakeholder Engagement," $1.1M ($1,101,350), FHWA, 9/19/13-9/18/16.
13. Bevly (PI/PD), Lim (co-PI), "Network Assisted Navigation," CERDEC, $2.1M, 10/1/2012-12/31/2015
14. Bevly (PI/PD), Flowers, "Vehicle Spacing Determination & Display In Low Visibility Conditions," IS4S (through Army SBIR), $345K.
15. Bevly (PI/PD), Sesek, Evans, "Extended Event Horizon Navigation & Wayfinding For Blind & Visually Impaired Pedestrians In Unstructured Environments, FHWA, $600K, 3/29/13-11/1/15.

16. Bevly (PI/PD), "GPS Study & Report," Defense Contractor, $154K, 5/21/13-6/14/14.
17. Bevly (PI/PD), "GPS Based Positioning System For Geophysical Surveys In Heavy Foliage Areas, IS4S, $200K, 5/1/13-4/29/16.
18. Bevly (PI/PD) "Support To Darpa All-Source Positioning & Navigation (ASPN) Phase 2," Leidos, $40K, 10/1/2013-9/15/2014.
19. Bevly (PI/PD), "Development & Testing Of Automotive GPS-DR System," Autotalks, $30K, 7/1/13-12/31/13.
20. Bevly (PI/PD), "GPS radio frequency signal recorder development," US Army AMRDEC (through Gleason), $58K, 10/1/2013-6/30/2014
21. Bevly (PI/PD), "Base Force Sensor Implementation For Angiography System Collision Detection," Siemens Medical, $41K, 12/17/13-12/16/14
22. Bevly (PI/PD), "Development of Enhanced GPS Signal Processing for Weak Signals," John Deere/Navcom, $210K, 11/1/2012-12/31/2015.
23. Bevly (PI/PD) "Modeling of Fiber Bragg Grating Strain Sensors," Draper Laboratories, $50K, 9/1/2012-6/30/2013
24. Bevly (PI/PD) "Software for a Mobile Autonomous Robotic Vehicle (MARV)," Honeywell, $20K, 9/1/2012-12/31/2012
25. Bevly (PI/PD) "Development of Adaptive implement Guidance (iGuide) Algorithms," John Deere, $120K, 11/1/2012-10/30/2014.
26. Bevly (PI/PD) "Implementation of DRTK and Tire Road Friction Estimation for AMAS," LMCO, $100K, 11/1/2012-10/30/2013
27. Bevly (PI/PD) "Missile Trade Studies," Sparta, $75K, 3/2013-11/30/13.
28. Bevly (PI/PD), "Vision Based Algorithms For Road Edge Detection, Continental Automotive," $30K, 1/1/2014-4/30/2014
29. Bevly (PI/PD), Sinha, S., "Stability Control Improvement & State Detection For Autonomous Vehicles," Autonomous Solutions Incorporated (through Army SBIR), $445K, 12/1/2012-6/30/2016.
30. Bevly (PI/PD) "Design of a Real-Time GPS Simulator using Software Define Radios," US Army AMRDEC, $70K, 10/1/2012-9/31/2013
31. Bevly (PI/PD) "Missile Guidance Technology Study-Part II," MSIC, $50K, 2/16/2012-2/15/2013
32. Bevly (PI/PD) "Navigation Algorithm and Analysis for a SUGV", Qinetieq NA, $125K, 2/15/2012-4/15/2013
33. Bevly (PI/PD) "Missile Guidance Technology Study," MSIC, $50K, 6/1/2011-5/30/2012
34. Bevly (PI/PD) "Visible Electrical-Optical (EO) Systems and Lidar Fusion for Low-Cost Perception by Autonomous Ground Vehicles," Robotic Research (for ONR STTR), $20K, 9/1/2011-12/30/2011
35. Bevly (PI/PD) "Investigation of IMU accuracy on Vehicle Navigation," SPAWAR, $26K, 7/1/2011-9/30/2011

36. Bevly (PI/PD) "Use of Multiple Antennas to Detect and Reject Multipath GPS Signals," US Army AMRDEC, $47K, 1/1/2011-12/31/2011
37. Bevly (PI/PD) "Investigation of Trailer Sway Detection using Low-Cost IMU Sensors," Synco Corporation, $25K, 5/1/2011-10/31/2011
38. Bevly (PI/PD) "Development for Vehicle Identification using Weigh In Motion Systems," IEM, $27K, 8/1/2011-12/31/2011.
39. Bevly (PI/PD) "Follow on to next Generation Vehicle Positioning Techniques in GPS-Degraded Environments for Vehicle Safety and Automation Systems," FHWA, $80K from 4/1/2012-12/31/2012
40. Bevly (PI/PD), Beale, Marghitu, "Collaborative Proposal on Investigation of New C-Arm Design and Collision Detection Methods ", Siemens, $75K, 10/1/2011-9/30/2012.
41. Bevly (PI/PD) "Vehicle Instrumentation and Modeling for Long Combination Vehicles," $103K, National Transportation Research Center, Inc., 12/1/2010-9/30/2011.
42. Lim (PI), Bevly (Co-PI) "Secure Area Networks for Heavy Trucks," $130K, National Transportation Research Center, Inc., 12/1/2010-9/30/2011.
43. Waggoner, P. (PI), Bevly (Co-PI), "Riverine IED Detector Dog: Expanding and Enhancing Expeditionary Dog Technology, $625K, (original award was $4.1M, but only $625K provide as Auburn terminated the award), Office of Naval Research, 10/1/2010-9/20/2011.
44. Bevly, (PI), Mao (Co-Pi), Lim (Co-PI), "SBIR AF093-048: Wi-Fi for Assured PNT and Integrity Verification ", 4/1/10-12/1/10, $15K, subcontract from IS4S
45. Hung, J. (PI), Bevly (Co-PI), "Navigation and Control of Towed Instrumentation," under a Cooperative Agreement between the US ARMY CORPS of Engineers and Auburn University, $1,336,587, ARMY Corp of Engineers, 3/24/06-6/1/12
46. Bevly (PI/PD), "Next Generation Vehicle Positioning Techniques in GPS-Degraded Environments for Vehicle Safety and Automation Systems," FHWA, $650K from 9/1/2009-8/31/2013
47. Bevly (PI/PD) "Demonstration of DRTK in CAST Program," Lockheed Martin Co., $30K, 1/10/10-6/10/10.
48. Bevly (PI/PD), "Integrated Sensor Measurement for Improved Chassis Control Systems," General Motors (through ARDI), $80K, 12/01/2009 – 03/31/2011.
49. Bevly (PI/PD) "Low-cost navigation in GPS denied environments," $65K, Army Research Lab (through GDRS), 10/1/09-8/31/10
50. Bevly (PI/PD) "Analysis of Dual Frequency DRTK and ANS Vehicle Model Development, $125K, General Dynamic Robotic Systems, 1/1/2010-12/31/2010.
51. Bevly (PI/PD) "Analysis of Dual and Single Frequency DRTK, $125K, General Dynamic Robotic Systems, 3/1/2009-12/31/2009.
52. Bevly (PI/PD) Vehicle Navigation Research, $125K, General Dynamics Robotic Systems, 3/1/2009-8/31/2009.
53. Bevly (PI/PD) "Title." $120K, Ford URP, 3/1/2008-2/28/2011.

54. Bevly (PI/PD), Jackson, R. (Co-PI), "Navigation and Modeling Algorithms for FCS Convoys," US Army TARDEC, $540K from 3/1/2008-2/28/2010
55. Bevly (PI/PD), "Intelligent Multi-Sensor Measurements to Enhance Vehicle Navigation and Safety Systems," FHWA, $320K from 9/1/2007-8/31/2009
56. Bevly (PI/PD) "Sensor Geo-Location for Large Scale Agent Defeat Testing, Science Applications International Corporation (SAIC) $25K, 10/1/07-3/31/08.
57. Bevly (Pi/PD) "Performance Analysis of Deeply Coupled GPS/INS Algorithms for Military Applications (Continuation)," U.S. Army Aviation and Missile Research Development Engineering Center, $83K, 9/1/07-8/31/08.
58. Bevly (PI/PD), Choe, "SBIR Phase II: A Hierarchical Fault Tolerant Control System for UGV Experiencing Mobility Failures" Global Technologies, Inc., $200K over 24 months.
59. Bevly (PI/PD), "Development of a RTK system: Design and Set-up", US ARMY TARDEC, $50K
60. Bevly (PI/PD), "Navigation and Control of the Oshkosh Urban Challenge Team," Oshkosh Truck, $150K 10/1/06-12/31/07
61. Bevly (PI/PD) "Travel for Terramax Testing and Integration," Oshkosh Truck Company, $8K
62. Bevly (PI/PD), "Study of the Use of Terrain Information to Improve Fuel Economy in Heavy Vehicles," Intermap Corporation, $40K, 1/1/07-9/30/07.
63. Bevly (PI/PD) "Sensor Geo-Location for Large Scale Agent Defeat Testing, Science Applications International Corporation (SAIC) $25K, 10/1/06-12/31/07.
64. Bevly (Pi/PD) "Performance Analysis of Deeply Coupled GPS/INS Algorithms for Military Applications (Continuation)," U.S. Army Aviation and Missile Research Development Engineering Center, $83K, 8/1/03-12/31/07.
65. Bevly (PI/PD), "On-line System Identification for Control of Unmanned Ground Vehicles," Army Research Office Young Investigator Proposal, $150K, 8/1/06-8/31/09.
66. Bevly (PI/PD), "Autonomous Navigation and Control of a K-9," Office of Naval Research Young Investigator Proposal, $300K, 5/1/06-5/31/09.
67. Bevly (PI/PD), "Relative Navigation and Control of Truck Convoys for FCS," SAIC, $350K, 1/1/06-1/31/08.
68. Bevly (PI/PD), "Enhancement of Lane Departure Warning Systems Using GPS," Nissan Technical Center, North America, $50K, 10/1/05-3/31/06.
69. Bevly (PI/PD), "High-Speed Tele-operation and Navigation of UGVs in Harsh Environments," U.S. Army Aviation and Missile Research Development Engineering Center, $100K, 4/1/05-4/30/06.
70. Bevly (PI/PD), "Development of Control Algorithms for DARPA Grand Challenge," Rockwell Collins and SciAutonics, $55K, 12/1/04-12/31/05.
71. Bevly (PI/PD), "Development of an Autonomous Ground Vehicle Sensor Suite Platform," Rockwell Collins University Grant Competition, $25K, 5/1/04-5/31/05.

72. Bevly (PI/PD), "Adaptive Ultra tight GPS/INS Coupling for High Anti-Jam GPS Guidance," MDA STTR with Phase IV Systems, $35K, 10/1/03-3/31/04.

73. Johnson (PI), Lall, and Bevly, "Electronic Packaging and GPS/INS Navigation of Small Unmanned Aerial Vehicles," Harris Corporation, $30K, 9/1/03-2/28/04 (Bevly's portion was $10K).

74. Bevly (PI/PD), "Performance Analysis of Deeply Coupled GPS/INS Algorithms for Military Applications," U.S. Army Aviation and Missile Research Development Engineering Center, $150K, 8/1/03-12/31/07.

75. Bevly (PI/PD), "Identification of Model Variations and Adaptive Control of Automatically Steered Farm Tractors Using GPS," John Deere and Company, $250K, 2/15/03-12/31/07.

Internally Funded Proposals

1. Bevly (PI/PD), "Determination of the Effect of Asphalt Types on Truck Fuel Economy," Auburn Competitive Research Grant Program, $10K, 3/01/04-3/31/05.

2. Bevly (PI/PD, Mentee) and Suhling (Mentor), "Diagnostics in Harsh Environments Using Wireless MEMS Sensors," Auburn Mentoring Program, $6K, 2/1/04-2/28/05.

9. Description of Scholarly Program

Dr. Bevly's research focuses on the robust control of autonomous vehicles using GPS and Inertial Navigation System (INS) sensors. This research consists of three main thrusts: sensor fusion/integration, on-line system identification, and adaptive control techniques and their application to vehicle dynamics and transportation. These methods can be used for such things as determining vehicle and driver models. Improved driver models could be used by a number of vehicle monitoring systems, i.e., safety systems that determine the effectiveness of a driver and increase road safety by removing fatigued or intoxicated drivers from the road. Vehicle modeling and state estimation is important in a number of current vehicle safety systems, such as ABS, traction control, and stability control. Additionally, future vehicle safety systems, such as driver assisted systems, adaptive cruise control, and even full autonomous lane-keeping, require precise vehicle models.

The first part of Dr. Bevly's research investigates methods for better calibration of the INS errors while GPS measurements are available, which will improve performance of the INS unit during periods when the GPS signal is obstructed (as well as between GPS measurements). Improved performance will be sought by including dynamic models of the vehicle system and incorporating these dynamic constraints with low-level INS/GPS measurements. Carrier-phase GPS signals, in conjunction with the system model, will be used to accurately calibrate the INS model and its errors. This precise calibration will provide a dead reckoning system, initialized using GPS, capable of providing accurate estimates of the vehicle states (position and attitude) for the continuous control of the vehicle during GPS outages. The integration of INS and GPS can be used to provide an unbiased, high-update estimate of vehicle states such as position, velocity, and attitude. This blended solution thereby provides accurate data for modeling autonomous vehicles. The ability to accurately determine the vehicle states as well as the vehicle model on-line, during changing environments, will in turn lead to an increase in the control performance of a vehicle. Finally, Dr. Bevly's research focuses on adaptive control and estimation algorithms for autonomous vehicles. On-line system identification techniques capture the changing

parameters of the systems, which can be used to adapt the control and estimation algorithms. Once techniques for using the GPS/INS solution to perform on-line identification have been developed, methods that adapt, or self-tune, optimal controllers and estimators (such as LQR and Kalman filters) can be investigated. The adaptation of the control and estimation algorithms to the continually identified model parameters will lead to accurate and robust performance of these autonomous systems.

Dr. Bevly also directs the GPS and Vehicle Dynamics Laboratory, which he created since coming to Auburn. Through Dr. Bevly's efforts, the laboratory has gained a significant reputation for producing outstanding engineers as companies seek to hire Dr. Bevly's students and collaborate with the lab on research projects. Dr. Bevly has also secured state-of-the-art equipment to be used in the lab, including various GPS receivers (including a software GPS receiver), Inertial Measurement Units (IMUs), an instrumented Infiniti G-35 (donated by Nissan), an automatically steered John Deere tractor, and access to an autonomous ATV. Projects include ultra-tight GPS/INS coupling (sponsored by the Army), study of vehicle rollover propensity, improved steering control of GPS guided farm tractors (sponsored by John Deere), vehicle and driver monitoring, and navigation and control of unmanned ground vehicles (UGVs). Dr. Bevly also leverages other resources at Auburn to expand his research. For example, the GPS and Vehicle Dynamics Laboratory utilizes Auburn's National Center for Asphalt Testing (NCAT) test track. Validation of Dr. Bevly's work can be performed using the semi-trucks at the test track or the lab's test vehicles.

C. Outreach

1. Commentary

a. Dr. Bevly has initiated several international interactions, promoting Auburn University worldwide including Mexico, Chile, France, and Sweden. The first interactions began with ITESM (known as Monterrey Tec) in Monterrey, Mexico. He made an initial trip in April of 2005, and was invited back in August of 2005 for one week. While on campus, he interacted with faculty and researchers and presented a talk about Auburn University to a freshmen engineering class as well as a research lecture to the faculty and graduate students. The collaborations with ITEMS are expected to grow over the next several years as researchers in several areas are excited about collaborating with Dr. Bevly and have written several letters of support for NSF proposals.

Dr. Bevly was invited to be a conference organizer and panel chair in Changchun China for the 2012 International Conference on Advanced Vehicle Technologies (VIT). Dr. Bevly has also established relationships with University Pierre and Marie Curie in Paris, France. He was invited to present a seminar on his research. Since that time, Dr. Bevly has hosted two French undergraduate students each of the last 4 summers in his lab from University Pierre and Marie Curie. Dr. Bevly has also had funding from Siemens Medical in Germany, in which 2 of his graduate students spent an internship with Siemens in Forcheim, Germany. This upcoming year, two of Dr. Bevly's graduate students will spend 6 months at Daimler in Stuttgart, Germany. Finally, Dr. Bevly has visited Chalmers University (giving a seminar), Volvo Cars (giving two presentation), and Volvo Trucks (also giving 2 presentations) all in Gothenburg Sweden. Dr. Bevly and one of his graduate student will collaborate with Volvo Trucks in a data collection

experiment this summer. Dr. Bevly has recently made two trips to Chile, giving seminars at two different universities. Dr. Bevly plans to continue this outreach, potentially teaching a class or short-course in Chile.

b. Dr. Bevly and his students have actively participated in the 2004 and 2005 DARPA Grand Challenge, a driverless vehicle race in the Mojave Desert (see pictures below). In 2004, Auburn teamed with SciAutonics, LLC and finished 7th out of 45 initial competitors. Only nine made it out of the starting gate. In 2005, Auburn again teamed with SciAutonics as well as participating with the Terramax team. The SciAutoincs-Auburn team was one of 10 selected early for competition (from a 7th place standing at the qualification), and finished 16th out of 195 initial competitors, while the Terramax team was one of the 5 vehicles to complete the Grand Challenge Course. The fact that the number of entrants increased more than fourfold indicates the response from the first Grand Challenge. Documentaries were made on numerous teams, some of which never made it to the final event. The Discovery Channel hosted several shows focusing on the event, NOVA developed a special summarizing the 2005 Grand Challenge, the Associated Press periodically published articles, and the winning vehicle is on temporary display in the Smithsonian National Museum of American History. Additionally, team Terramax reported that their website (which lists a link to Dr. Bevly's lab as a team member) had over 500,000 hits during the course of the 2006 DARPA Challenge. SciAutonics also lists Auburn on their website. Furthermore, Oshkosh Truck, the lead for team Terramax, estimates that the media exposure of their vehicle reached over 16 million people. Within all of this publicity, the Auburn University Logo could be easily seen on the vehicles that Auburn teamed with in this historic and prestigious contest.

SciAutonics-Auburn Engineering Team

Team Terramax at the Finish Line

Dr. Bevly and Graduate Student William Travis with the Terramax Vehicle displaying the Auburn University Logo.

2. Activities and Products

b. Instructional Activities - Refer to "3. Papers and Lectures" on page 9.

c. Technical Assistance

Dr. Bevly has served as a consultant for the following companies:

1. IS4S, "Navigation Algorithms"
2. Morgan Research Corporation, "Feedback control of a MEMS gyroscope."
3. Rockwell Scientific, "Control of a UGV for the DARPA Grand Challenge."
4. SAIC, "GPS/INS Requirements for Future Combat Systems (FCS)."
5. Joe Gibbs Racing

e. Outreach Publications - None.

f. Electronic Products - None.

g. Other Outreach Products - None.

h. Copyrights, Patents, and Inventions - Refer to "6. Patents and Inventions"

i. Contracts, Grants, and Gifts

Dr. Bevly has received two monetary gifts and has secured the use of equipment to aid in his research.

1. Alumni James Sherman gave a $1000 gift to Dr. Bevly, which was used to build a GPS/INS data collection box for use in the classroom.
2. Former student Joseph Manusakis gave a $100 gift, which was matched by his employer, KPMG Foundation, resulting in a total donation of $200; the gift will be used to build a motor demonstration for use in MECH 3140.
3. Dr. Bevly has secured various equipment during his tenure at Auburn (some loaned and some donated) from the following companies: Nissan has loaned two Infiniti G-35 Sedans (one loaned 4/1/2005 and the second loaned

11/1/2009) and an Infiniti M-45 (loaned 8/1/2005) to be used for testing at the NCAT test track; SciAutonics has donated two ATV Corp All Terrain Vehicle (donated 7/1/2005) to be used for UGV navigation and control; and John Deere and Company has loaned an 8420 auto-steer tractor (loaned 6/1/2003) to be used as a test-bed for Dr. Bevly's John Deere research; and finally 2 Peterbilt tractors (loaned 9/1/2014) and UPS trailers (loaned 2/15/2015) for the FHWA Research project. Please see pictures below of a few of the vehicles.

D. Service

1. University Service

Auburn University Faculty Research Council (FRC) 2013-2015.

Member of Faculty Search Committee, 2005-2006.

AU College of Engineering Graduate Recruitment Committee (2007-present)

AU Department of Mechanical Engineering Graduate Program Committee (2009-present)

2. Professional Service

Chair of the Editorial Board (CEB) for ASME Dynamics Systems and Control (DSC) Division (2012-2015)

ASME DSC Automotive and Transportation Systems Technical Committee

- Chair, 6/1/2007-5/31/2009
- Vice Chair, 6/1/2004-5/31/2007

Editorial Board of the International Journal of Autonomous Vehicle Systems (2009-present)

Associate Editor for the ASME Dynamic Systems and Control Conference (2009 and 2010)

Associate Editor for the American Control Conference (2010)

Session Organizer for the Automotive and Transportation Panel technical sessions at the 2002, 2003, 2004, and 2005 ASME IMECE Conferences

Session Chair: 2000 and 2002 ASME IMECE Conferences; 2000, 2001, and 2002 American Control Conferences

Journal Reviews: Journal of Vehicle System Dynamics, IEEE/ASME Transactions on Mechatronics, ASME Journal of Dynamic Systems Measurement and Control, International Journal of Field Robotics, International Journal of Vehicle Autonomous Systems, International, Journal of Vehicle System Modeling and Testing, Electronic Letters, Sensors, Transactions on Vehicular Technology, IEEE Transactions on Intelligent Transportation Systems

Proposal Reviewer: NSF Review Panel for Sensor Technologies for Civil and Mechanical Systems unsolicited proposals

Memberships

1. American Society of Mechanical Engineers
2. Association of Unmanned Vehicle Systems
3. Institute of Navigation
4. Society of Automotive Engineers