Part 1. COVER SHEET (see attached)

Part 2. Identification and Significance of the Problem or Opportunity

The integration of Global Positioning Systems (GPS) and inertial measurement units (IMU) for vehicle navigation systems has seen recent success [1]. These inertial navigation systems (INS) rely on inertial sensor technologies that are well-established and accurate, yet tend to have bulky packages and significant power consumption. While this is not a serious hindrance for application to vehicle navigation, the additional weight capacity and power requirements make application to man-portable devices a challenge. Additionally, man-portable devices that are used for locating far-targets usually make use of magnetometers which are prone to pervasive magnet noise in the field.

The recent introduction of inexpensive MEMS gyroscopes into the sensor market brings the opportunity for greater flexibility in possible applications. The advantage of these sensors lies in the ability for a designer to introduce inertial data into smaller applications. There is also significantly reduced cost as compared to traditional inertial sensor technologies. The advent of MEMS based IMU technology presents the opportunity to create INS systems similar to their vehicle counterparts for applications that are easily man-portable and that have little or no dependence on magnetometer technology.

Over the past decade, the availability of inexpensive GPS positioning systems has increased dramatically, allowing accurate localization in all types of environments. The value of this newly-available information in compact and inexpensive forms is invaluable, and GPS has already been exploited quite effectively by both civilian and military users. One of the greatest challenges that is associated with using MEMS-based IMUs is the significance of random bias errors. These errors may be reduced significantly by utilizing data from a GPS in conjunction with advanced processing techniques [2]. The value of the inertial data can be increased significantly while maintaining the benefit of low weight and cost necessary for a man-portable targeting device.

Part 2.1. Background

Global Positioning Systems and Inertial Measurement Units

An inertial navigation system is designed to measure position and orientation of a person or object. At the heart of the INS is an IMU. The IMU is a self-contained sensor module consisting of at least three accelerometers and three gyroscopes. The accelerometers measure acceleration along each of the three cardinal axes of the object of interest as referenced to a global coordinate system. If the initial location of the sensor is known, the position as a function of time can be calculated by multiple integration of the measured acceleration. The three gyroscopes measure rate of angular rotation and are used to determine vehicle orientation. Accelerometers may also be used to measure the local gravity vector for additional orientation information. The use of an INS in vehicle navigation is attractive especially in hostile environments because, unlike GPS sensors, the IMU is self-contained and not susceptible to jamming, and can provide acceleration information under extreme, dynamically intense, environments provided there are sufficient measures taken to screen random vibration and shock events. The main drawback of an IMU in general is that position errors accumulate over time due to a variety of errors inherent in all IMU sensors.

Motivation

The motivation for the Phase I investigations will be to determine the feasibility of designing an INS of sufficiently small size for man-portability that can support attitude angle resolution approaching the order of 0.3° (5.2 mrad). The limiting dynamic variable in these man-portable far-target location devices will likely be the measurement of azimuthal angle due to the inherent white noise associated with MEMS based gyroscopes and the accumulation of angle measurement error resulting from the required integration. The final result of Phase I shall be to reveal what the limits of the available MEMS inertial sensors are and to determine how close to the target resolution of 0.3° we can achieve.

Essential components of the INS for man- portability

There are three main divisions of the proposed INS:

1. MEMS based IMU with bias compensation capabilities.
2. Compact and inexpensive GPS unit.
3. Data acquisition and processing module for A/D conversion, signal processing, and implementation of Kalman filter/estimator.

MEMS-based IMU

MEMSense has years of experience in the design and manufacture of MEMS-based inertial measurement devices that include gyroscopes and accelerometers. We are an industry leader in the integration of MEMS gyroscopes which appeared on the market in 2003. The MEMSense nIMU (Fig. 1) is one such device that provides triaxial angular rate , triaxial acceleration, and triaxial magnetic data output. The inertial sensor output is digitally sampled for on-board corrections to temperature drift and cross-sensitivity in the gyroscopes and accelerometers. Bandwidth is sufficient for use in a man-portable device according to biometric data.

MEMSense nIMU

- *3D Angular Rate*
- *3D Linear Acceleration*
- *Magnetic compass*
- *Digital output with corrections to temperature drift and cross axis sensitivity in gyroscopes and accelerometers*

Figure 1: MEMSense nIMU developed for a biofeedback suit as part of SOCOM Phase II award: *Dimensions in inches*.

Compact, Low-Cost GPS

GPS can be used to determine position within about a 10 meter radius using a single receiver [3]. Differential GPS (DGPS), which incorporates differential corrections from a fixed base station, can eliminate most of the remaining errors and enable positioning to within a meter and even down to a few centimeters. Multiple antennae GPS units have been shown to be capable of providing vehicle attitude measurements down to 0.1 degrees [4]. The ability to measure position and attitude on vehicles has led to many advances in land, marine, and air navigation systems. In automotive applications, the positioning capability of GPS has proven effective when implemented for land navigation [5]. GPS also has been used to develop automatically steered farm tractors[6] and autonomous ground vehicles (UGVs) for the military[7,8]. The additional space and weight saved by using a MEMS-based IMU will open a multitude of new applications well beyond those of vehicle navigation.

Data acquisition, memory, and processing unit

The overall processing architecture will consist of three processing levels: central processor (CP), digital signal processor (DSP) and a programmable logic device (PLD) in order to connect the various devices and apply the Kalman estimation algorithm.

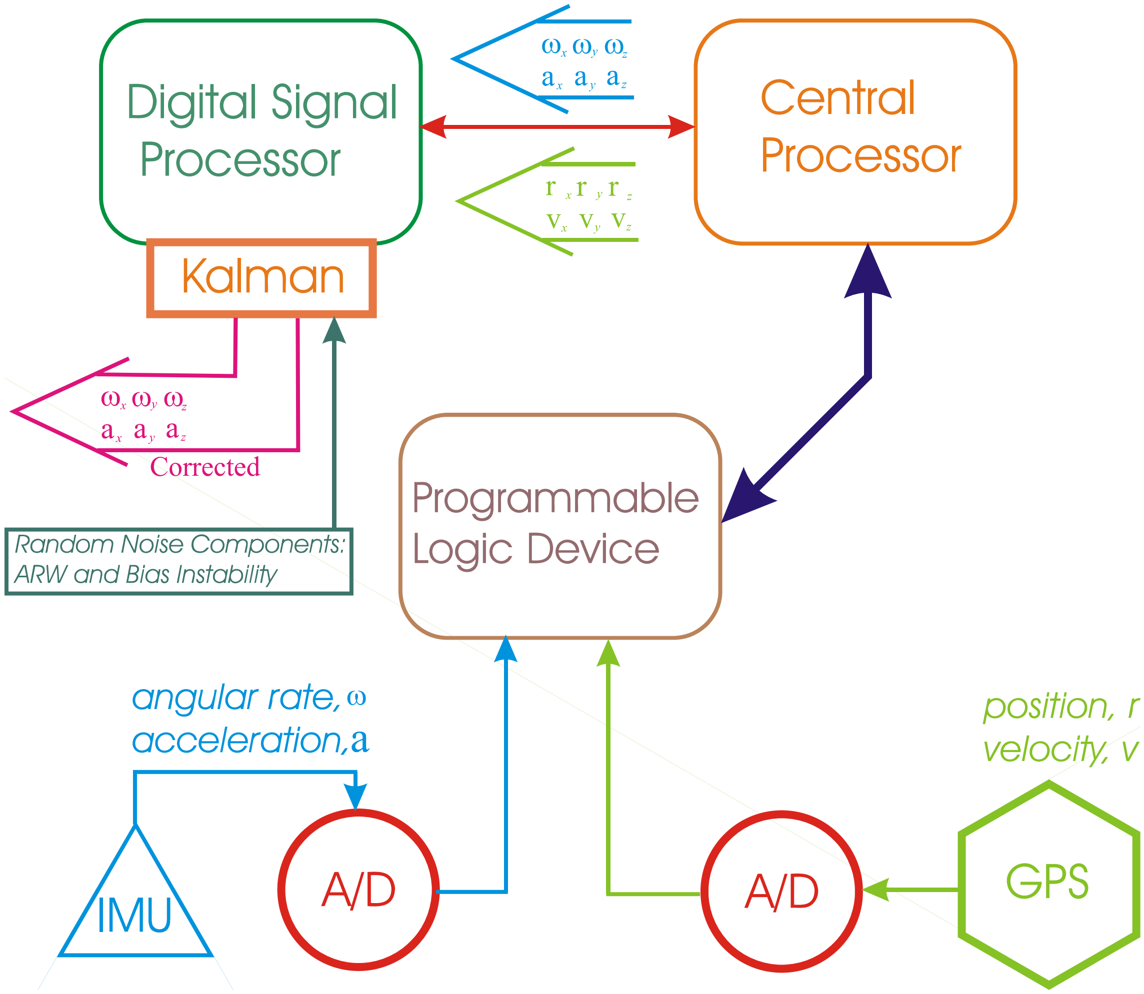

Figure 2: INS Component Architecture

The PLD will perform acquisition and interfacing of data from the IMU and GPS. Another task of the PLD will be to transfer data for the DSP. The Digital Signal Processor performs data processing routines for the system. During the investigations related to feasibility of such as system, a PC may be utilized with an appropriate data acquisition system. This system's function revolves around determining the current state of the GPS/IMU output and the application of a Kalman estimator algorithm.

Part 2.3. Utilizing GPS Data for IMU Corrections

The core of the investigations will be to utilize of a Kalman filter to optimally integrate the GPS and IMU measurements. The Kalman filter incorporates results from the analyses of raw IMU data and the velocity measurements from the GPS unit which then feed into a position Kalman filter. A standard Kalman Filter can be used to estimate the velocity, attitude and inertial sensor drift using an advanced model representation of the inertial sensors.

Part 3. Phase I Technical Objectives

The result of our investigations will be to find the limits of a INS that makes use of MEMS based inertial sensors. First, a development IMU will be constructed that makes use of the most accurate MEMS based gyroscopes and accelerometers available today and evaluated for performance as part of an integrated IMU/GPS/Kalman system with the express goal of reaching attitude measurement resolutions on the order 0.3°. If this performance can be demonstrated in a timely fashion, additional work will begin to optimize this system with the aim of reducing the systematic noise inherent to the MEMS gyroscopes. The main result of these investigations should be a complete evaluation system capable of melding GPS derived data with IMU data for a specific set of sensors The signals from these two systems will be subject to processing through a Kalman estimator that has been tuned via parameters determined from raw IMU sensor data.

The first task in Phase I will be the selection and evaluation of candidate MEMS gyroscope and accelerometer technologies currently on the market. This includes the reevaluation of the products currently used by MEMSense in our product line The model for the resultant IMU will have its basis in the current MEMSense IMU's manufactured by MEMSense for aerospace applications which have the most accurate (least noise) inertial specifications.

Phase I objectives are as follows:

1. Design and develop a sensor board for the evaluation of inertial sensor candidates.

2. Retrofit an existing MEMSense PCB or design a development PCB for accepting the candidate devices.

3. Integrate the candidate IMU sensor module and a processor board into a functioning system.

4. Characterization of the noise components for IMU.

    a. Determination of temperature drift over operating range
    b. Determine effect of cross sensitivity
    c. Calculate and apply 2nd order corrections to temperature drift and cross sensitivity
    d. Conduct Allan variance data collection and analysis including the determination of the following parameters:

        - Angle Random Walk
        - Bias Instability
        - Rate Random Walk
        - Other noise random noise components affecting the total bias drift.

5. Select and obtain a suitable GPS for integration into the INS.

6. Development of GPS/IMU interface with aid of PC or extension of development board.

7. Deployment of Kalman estimator, initial data collection and tuning iterations.

Part 4. Phase I Work Plan

Task 1. Evaluate Current MEMS Gyroscope and Accelerometers for IMU

This will be defined by the development of a concept IMU device based on high performance MEMS devices. The IMU will be assembled and the ability to digitally sample and manipulate the output of these sensors will be established. This process will go rather quickly due to the extensive experience in rapid development of new inertial sensors into IMU devices that is associated with the R&D team at MEMSense.

Task 2. Characterization of the Candidate Inertial Sensors

Raw data will be collected in a variety of environments to characterize systematic errors in the concept IMU. This includes temperature bias drift, and cross-sensitivity in gyroscope and accelerometers.

Task 3. Random Noise Component Analysis

Random noise components will be determined at this time via Allan Variance methods. There are numerous types of stochastic processes that are present in inertial sensors that dominate at varying time scales. The focus of the study will be to confirm the nature of the random processes involved in the random bias drift and to quantify these components.

Task 4. Kalman filters form the core of our sensor fusion approach, but the proposed work emphasizes integrating the GPS and inertial sensors together at several additional levels using a variety of different algorithms. Theoretically, this type of multiple coupling violates the independence assumptions in the Kalman filter. However, past practical experience suggests that this sacrifice is justified in order to increase the speed and accuracy of the computations, and to avoid incorporating spurious results (i.e., noise which is not well modeled by Gaussian estimates) into the filters. For this application we believe that GPS and IMU data can be productively fused using the following guidelines:

1. Resulting analysis of the sensors will be exploited in order to improve the efficiency and the accuracy of Kalman filtering algorithm
2. Results from the GPS based data will be used to validate results from the inertial system data.
3. Results from the inertial system will be used to validate results from the GPS velocity calculations.
4. A Kalman filter will be used to integrate GPS data and acceleration/rotational velocity estimates from the inertial system.

The core of the analysis consists of a Kalman filter to optimally integrate the GPS and IMU measurements. The Kalman filter incorporates results from the IMU and the velocity measurements from the GPS unit which then feed into a position Kalman filter.

Part 5. Related Work

MEMSense: Experience with precision MEMS IMUs

MEMSense has been producing MEMS based inertial measurement devices for over three years. Our company began with the design of analog triaxial gyroscope modules for use in biofeedback systems for the Navy. The years following that time have seen the development of more and more sophisticated IMUs with increased functionality and error correction methods. Today, we manufacture and market two IMU devices for the public sector that both contains MEMS gyroscopes, accelerometers, and a solid-state triaxial magnetometer all integrated with onboard digital sampling and signal conditioning. The raw sensors outputs are corrected for temperature variations in bias over a range from negative 40°C to +85°C as well as for cross axis sensitivity. MEMSense has also developed. We also manufacturer a number of IMUs as part of military projects that have additional corrections to bias from acceleration effects.

Auburn University: Experience with GPS/IMU integrated INS

The GPS and Vehicle Dynamics Laboratory at Auburn University has a multitude of GPS receivers and software to process both the GPS measurements and the GPS/INS measurements. Software is readily available to fuse the

GPS and INS measurements and compare the actual accuracy to Monte-Carlo simulations which use the GPS and IMU sensor models. Some relevant work that has been conducted at the lab:

Autonomous Navigation and Control of a K-9 (Office of Naval Research)

The GPS and Vehicle Dynamics Laboratory at Auburn University is currently funded to develop navigation and control algorithms for a trained K-9. The first part of this project involves development of a GPS/INS pack to determine the location, orientation, and motion of the K-9. The pack consists of a small OEM GPS receiver, MEMS accelerometers and gyroscopes, micro-controller, and wireless communication device to transmit the data to a user.

Related Work Carried Out by Auburn Researchers

1. Modeling and Navigation for Precise Relative UGV Control (FCS LSI)

2. Design and Sensitivity Analysis of Deeply Integrated GPS/INS Algorithms for Navigation (US ARMY AMRDEC)

3. Sensor Geo-Location for Large Scale Agent Defeat Testing, Science Applications International Corporation (SAIC)

4. "Performance and Sensitivity Analysis of Deeply Coupled GPS/INS Algorithms for Military Applications." Relative Navigation for FCS:

   As the principle investigator Dr. Bevly is providing the Aviation and Missile Research, Development, and Engineering Center (AMRDEC) at the Redstone Arsenal details on the inherent limitation of deeply coupled algorithms. The work includes analyzing various grade IMUs to determine navigation performance and jamming resistance of a deeply coupled GPS/INS system. A GPS emulator and software receiver is being built to test deeply coupled GPS/INS algorithms. The simulator will include realistic IMU data using noise, latency, and bias drift characteristics determined from analyzing the IMUs. Arrangements have been made to collect GPS and IMU data (from various IMUs used by the military) on a jamming range at Redstone Arsenal to verify simulated performance bounds.

5. "Relative Navigation for Military Convoys"

   The GPS and Vehicle Dynamics project is developing relative navigation algorithms using GPS and INS measurements for military convoys funded by the FCS LSI. GPS equipment is available at Auburn to test all of the developed algorithms as well as study the performance available under a wide range of conditions. The work is being validated on test vehicles at Auburn instrumented with GPS receivers and various grade IMU sensors.

Part 6. Relationship with Future Research or Research and Development

The Phase I activities will establish the feasibility of producing accurate orientation data with the proposed system. If the resulting system is indeed feasible, the focus of Phase II would be to redesign the system in order to obtain the full potential of the navigation device. This includes:

1. Design of packaging of the INS in regards to the ergonomics of man-portable equipment.
2. Additional collection and analysis of inertial sensor data to attain the best possible tuning parameters for the Kalman filter.
3. Redesign of Processing architecture for reduced size and cost.

Part 7. Commercialization Strategy

MEMSense Company Information

Origin

MEMSense began originally as the Qualvox Corporation in October, 2001. The Company existed as a software and electronics development consulting firm, but in October, 2002, transitioned to inertial product development. In mid 2003 Qualvox Corporation began doing business as MEMSense in the interest of presenting a corporate identity more closely aligned with its product offering. MEMSense received seed funding in late 2003 through a regional venture capital firm interested in nurturing high-tech companies in western South Dakota. In 2003, MEMSense won a two-year Phase II SBIR contract with the United States Special Operations Command, in which the Company is developing a networked micro inertial sensor system to analyze hazardous environments in which Special Operations Forces operate. Under this Phase II SBIR MEMSense developed 6 inertial products that have generated combined total revenues of over $1 million USD. MEMSense is aggressively marketing and selling its products through direct sales in the U. S. and distributors internationally. MEMSense customers include such companies as: Nissan, Centers for Disease Control, Samsung and the Jet Propulsion Laboratory.

*Vision & Pla*n

The MEMSense vision is to become a leading designer, manufacturer and volume supplier of innovative Micro Electro Mechanical Systems (MEMS) inertial sensors and systems. It is our goal to offer customers MEMS inertial sensors and integrated inertial systems that exhibit revolutionary accuracy, precision and micro-size at a competitive price.

Commercialization Potential

Handheld electronics have held a long fascination with general public. Consumers can not seem to get enough personal location data. As more functionality has become available with the miniaturization of digital processors and the parallel innovations in wireless communication, it is safe to say that GPS receivers have been a great success in the personal handheld electronics realm. It is not unreasonable to expect consumers to find uses for real time motion and attitude sensing for a variety of recreational activities. More importantly it can be readily understood that precision navigation that goes beyond the limits of a stand alone GPS unit will be of enormous value for emergency professionals of all kinds.

Even the most conservative estimates have show excellent growth in the sales of MEMS gyroscopes since their introduction to the market (Table 1).

	2002	2003	2004	2005	2006	2007	2008	2009
Units (M)	7.3	13.9	19.0	25.6	34.3	49.4	68.0	86.2
Growth Rate		90.3%	36.5%	34.9%	34.2%	43.8%	37.8%	26.7%
Revenues (USD M)	$279.0	$450	$536	$639	$762	$908	$1,083	$1,187
Growth Rate		61.3%	19.2%	19.2%	19.2%	19.2%	19.2%	9.6%

Table 1:Updated Worldwide MEMS Gyro Sales 2002-2009

Besides the potential for success in the field of defense, the commercialization of the resulting devices from these investigations have excellent potential for sales in the public sector. The remarkable popularity of GPS units in themselves displays the great desire for consumers to utilize position information especially in leisure activities.

Commercialization Plan

MEMSense in conjunction with the GPS Vehicle Dynamics Laboratory at Auburn University will progress through the research of the feasibility of a sufficiently accurate man-portable navigation system. The goal of these activities will result in the best possible navigation system with an emphasis on enhancement of data from gyroscopes and accelerometers. The intention will be to have a product that can be commercially licensed through leading navigation equipment manufacturers. To this end, MEMSense will explore the possibility of a partnership with a customer that specialize in the manufacturing navigation systems. MEMSense has many customers that are amongst the most innovative companies in regards to navigation systems. We are well poised to establish such a relationship in industry based on our relatively long history with these systems.

Part 8. Key Personnel

Samuel B. French - PI
Company: *MEMSense, LLC, Rapid City, South Dakota*

Professional Experience:

January 2004 to Present
R&D, MEMSense, LLC.
Associate Research Scientist –Mr. French's focus at MEMSense has included the design of MEMS sensors and characterization of noise in novel MEMS gyroscopes. He has characterized systematic and random noise in MEMS devices in various levels of integration with inertial measurement systems, and been key to the development of innovative correction algorithms. This includes the development of methods for compensation of systematic noise components in MEMS inertial sensors. Some experience highlights related to MEMS.

1. Development of vibration testing and specification for military applications involving MEMS IMU in the vicinity of pyrotechnic shocks.
2. Design of novel MEMS gyroscopes.
3. Analysis of temperature hysteresis and corrections in MEMS accelerometers.
4. Algorithm development for systematic error corrections.
5. Mathematical development of corrections to manufacturing imperfection in MEMS devices.

Dec 2000 to December 2002
Department of Physics, South Dakota School of Mines and Technology
Research Assistant – Supervisor: Dr. Michael G. Foygel
Development of computer models of 2-D and 3-D composite materials (carbon nanotube suspensions). Analyzed phenomena related to the critical onset of conductivity via applied site percolation theory. Determined the dependence of aspect ratio on the critical concentration of nanotubes in infinitely large disordered systems as seen in 'anomalous' data from experiments with high aspect ratio nanotubes in suspension.

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***Education*:**

2002
M.S. in Materials Science (*Department of Physics*)
South Dakota School of Mines and Technology
Thesis: *Monte Carlo Simulations of Nanotubes in Suspension: Random Site Percolation as Applied to the Critical Onset of Conductivity in Large Disordered Systems in Three Dimensions.*

1999
B.S. in Physics
South Dakota School of Mines and Technology
Senior Project: *Tuned Cross Diode Multiplexer for Nuclear Magnetic Resonance Stimulation and Detection.*

David M. Bevly, Ph.D. – Co-PI
Company: *Department of Mechanical Engineering, Auburn University*

Professional Experience:

August, 2001 to Present	**Department of Mechanical Engineering, Auburn University** **Assistant Professor –** Dr. Bevly's research focuses on sensor fusion algorithms, specifically GPS/INS sensor fusion, as well as on-line parameter estimation and system identification using GPS and inertial sensors. Dr. Bevly is building a research laboratory (as well as educational resources) for the development of GPS and INS algorithms and their application to vehicle control systems.
Sept., 2002 to Present	**Morgan Research** **Engineering Consultant –** Currently developing feedback control algorithms to force balance a vibrating MEMS gyroscope for improved sensing performance. Providing technical expertise to identify the dynamics of a prototype gyroscope and implement the control algorithm on a micro-controller.
Sept., 1997 to August, 2001	**Department of Mechanical Engineering, Stanford University** **Research Assistant –** 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. Initiated research on the use of GPS velocity measurements for estimation of vehicle states and developed a method for measuring wheel slip and sideslip angle. Developed methods to utilize GPS/INS integration on passenger cars for vehicle state and parameter estimation. All of these works have included developing vehicle simulation models and performing experiments on test vehicles to verify methodologies.
Sept., 1995 to Sept., 1997	**Department of Mechanical Engineering, M.I.T.** **Research Assistant –** Performed research and experimentation of planning and control techniques on an experimental climbing robot. Developed a simplified computed torque control technique for mobile robots and verified the algorithm on the climbing robot. Modified an action module planning technique to incorporate specifics of the climbing robot for verification of the planning methodology. Created computer simulations for a graphical interface to study the system. Performed research and hands-on design of modular field robotic systems. Aided in research and development of control and design of fixed-base robotic manipulators and mobile robotic systems. Responsible for electrical and mechanical hardware, as well as software to interface between experimental systems, sensors, and computer hardware.

Education:

Sept. 2001	Ph.D. in Mechanical Engineering Stanford University, Stanford, CA Dissertation: *High Speed, Dead Reckoning, and Towed Implement Control for Automatically Steered Farm Tractors Using GPS*
August 1998	M.S. in Mechanical Engineering Massachusetts Institute of Technology (MIT), Boston, MA Thesis: *Action Module Planning and Cartesian Based Control of an Experimental Climbing Robot*
May 1995	Bachelor of Mechanical Engineering Texas A&M University, College Station, TX

Professional Memberships:

ASME	*SAE*
Institute of Navigation	*AUVSI*

Most Relevant Publications to this Proposal:

1. Bevly, D. M., "GPS: A Low Cost Velocity Sensor for Correcting Inertial Sensor Errors on Ground Vehicles," *Journal of Dynamic Systems, Measurement, and Control*, Vol. 126, No. 2, June 2004, pp. 255-264.
2. Travis, W., Bevly, D.M., "Navigation Errors Introduced By Ground Vehicle Dynamics," *Proceedings of the 2005 ION GNSS*, Long Beach, CA, September 13-16, 2005.
3. Hamm, C., Bevly, D.M., "Simulated Performance Analysis of a Composite Vector Tracking and Navigation Filter," *Proceedings of the 2005 ION GNSS*, Long Beach, CA, September 13-16, 2005.

Mike Gibson *– Electronic Design*
Company: *MEMSense, LLC, Rapid City, South Dakota*

Technical Skills

PCAD, Protel
VHDL, AHDL
Altera, Xilinx
Visual SourceSafe, Razor, SVN
Compilers for embedded processors
MATLAB
Solidworks
Visual Studio – C++ and Basic

Applications Experience

C and Assembly for embedded processors
Real time processing
Printed Circuit Board design and layout
Serial Data Communications - RS232, RS422, I2C, SPI
Mixed signal hardware design.

EXPERIENCE

2005 - Present **Electronics Design Engineer, MEMSense,** Rapid City, SD

1999 - 2005 **Lead Engineer, NLX Corp,** Ellsworth Air Force Base
Manager of engineering group responsible for supporting hardware and software modifications and upgrades on simulators for the B1-Bomber. System consisted of a PowerPC running VxWorks with a UNIX interface. Software development in Ada, Visual Basic, and C.

1997-1998 **Digital Electronics, and Embedded Processor Design, Northwest Logic Design,** Hillsboro OR.
- C code and assembly for 68331 device drivers, RS232, IIC, real time control for an SXGA Portable Video Projector manufactured by Lightware, Inc.
- SXGA video display controller, using Altera 10K20, 7256, and 7064 running at 50 MHz. Interface to 8051 microcontroller, FIFO's, SGRAM. C code for 8051. RS232 interface to PC.
- Xilinx FPGA for a video flat panel display.

1995-1997 **Digital Electronics, and Embedded Processor Design, Electro Scientific Industries,** Portland, OR.
System level design of digital electronics and embedded software involving interface with analog, mechanical, and software systems for next generation of laser trimmers:
- Embedded processor board using four TMS320C32 DSP's with an ISA Bus interface, used for servo control of motors and positioning systems plus provides control and communication.
- Altera FPGA's and EPLD's for external and memory interface, serial data transmission to DAC's and ADC's, motor amplifier and encoder feedback, and control of actuators and sensors.
- System level architecture of control systems, motors, actuators, electronic interface.

1989-1995 **Ordnance Officer, U. S. Army and South Dakota National Guard**
Responsible for teams of up to 50 people in crisis situations. Coordinated resources and assets for a general support organization.

EDUCATION

South Dakota School of Mines & Technology (SDSM&T), Rapid City, SD
2002 Master of Science in Electrical Engineering
1993 Bachelor of Science in Electrical Engineering
University of Wyoming, Laramie, WY
1989 Bachelor of Science in Mechanical Engineering

Part 9. Facilities/Equipment

MEMSense – *Manufacturing Facilities and R&D*

MEMSense manufactures and develops the world's smallest inertial measurement units and sensors. The manufacturing and test facilities existing at MEMSense will benefit this research effort. The following list of equipment resources may be utilized in this effort:

1. Multiple precision angular rate tables with thermal environment capability from -60 C to +150C.

2. Centrifuge table with thermal environment capability from -60 C to +150C.

3. Shock vibration test station with capabilities to 4000g.

4. Valuable Experience with the use of MATLAB and SIMULINK:

    - Modeling and simulation of dynamic systems.
    - Feasibility of inertial measurement systems for specific applications.
    - Systematic noise reduction in MEMS-based inertial measurement units.
    - Allan Variance and PSD analysis as related to Random Noise modeling of MEMS inertial sensors.

Auburn University - *The GPS Vehicle Dynamics Laboratory*

The GPS Vehicle Dynamics Laboratory focuses on the control and navigation of vehicles using GPS in conjunction with other sensors, such as Inertial Navigation System (INS) sensors. The laboratory has several research thrusts including: sensor fusion/integration, on-line system identification, adaptive and robust control algorithms, and vehicle state and parameter estimation. These research thrusts are focused towards vehicle dynamics and transportation, including heavy trucks, passenger cars, off-road vehicles, as well as autonomous and unmanned vehicles. The laboratory consists of various GPS receivers, Inertial Measurement Units (IMUs), and test vehicles. Current projects include ultra-tight GPS/INS coupling (sponsored by the Army), study of vehicle rollover propensity (in collaboration with NHSTA), 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).

The laboratory also has access to data logging on semi-trucks used at the National Center for Asphalt Technology (NCAT) pavement test track located near Auburn University (http://www.pavetrack.com). The 2-mile oval test track has four trucks driving on the track 16 hours a day (each driver performing an 8 hour driving shift). Additionally, the track is broken into 200-foot sections of different pavement types. Detailed information on each section of the track is monitored including rut depth and coefficient of friction. Eight-hour driver shifts, changing rut depths, and detailed tire logging make the facility an ideal location for testing the algorithms developed under this research. GPS and inertial sensors can be mounted on a truck to validate proposed INS/GPS methods.

Instrumented Tractor-Trailer

Auburn University's NCAT Test Track

Part 10. Subcontractors and/or Consultants

Dr. David Bevly – Department of Mechanical Engineering, Auburn University.

Dr. Bevly laboratory expertise and extensive experience with the integration of GPS and IMU technology as applied to navigation makes him an ideal resource for the development of such systems.

Part 11. Prior, Current, or Pending Support of Similar Proposals or Awards

There is no prior, current, or pending support for the proposed work.

Part 12. COST PROPOSAL (see attached)

Part 13. References

1. Bevly, D. M., "GPS: A Low Cost Velocity Sensor for Correcting Inertial Sensor Errors on Ground Vehicles," Journal of Dynamic Systems, Measurement, and Control, Vol. 126, No. 2, June 2004, pp. 255-264.

2. Ibid.

3. Parkinson, B.W., and Spilker, J.J., ed., 1996, *Global Positioning System: Theory and Applications, Volume 1*, AIAA.

4. Cohen C.E., Parkinson, B.W., and McNally, B.D., 1994, “Flight Tests of Attitude Determination Using GPS Compared Against an Inertial Navigation Unit,” *Navigation: Journal of the Institute of Navigation*, 41(1), pp. 83-97.

5. Abbot, E., and Powell, D., 1999, “Land-Vehicle Navigation Using GPS,” *Proceedings of the IEEE*, 87(1), pp. 145-162.

6. Bevly, D.M., Gerdes, J.C., and Parkinson, B., 2002, “A New Yaw Dynamic Model for Improved High Speed Control of a Farm Tractor,” *Journal of Dynamic System Measurement and Control*, 124(4), pp. 659-667.

7. Baeder, B.T., Osborn, C.T., and Rhea, J.L., 1994, “Low cost navigation technology investigation for the unmanned ground vehicle program,” *Proceedings of the 1994 Position Location and Navigation Symposium*, pp. 574-580.

8. Bruch, M.H., Gilbreath, G.A., Muelhauser, J.W., and Lum, J.Q., 2002 “Accurate Waypoint Navigation Using Non-Differential GPS,” *Proceedings of the AUVSI Unmanned Systems Symposium*.

Cost Proposal

Cost Breakdown Items

1. *Name of offeror*
MEMSense, LLC

2. *Home office address*
2693D Commerce Rd.
Rapid City, SD
57702

3. MEMSense, LLC
2693D Commerce Rd.
Rapid City, SD
57702

4. Title of proposed effort:
"Enhanced Attitude Measurements for Dead Reckoning of Far-Target via Advanced Tuned Kalman Filter in integrated GPS/IMU man-portable Device"

5. Federal taxpayer ID #: 46-0463377
CAGE code: 1XBY2

6. Topic number: A07-085
Topic title: "Improved Far-Target Location Accuracy for Man-portable Systems Through Application of GPS, Gyroscope, and Magnetometer Technologies"

7. Total dollar amount of the proposal:
Phase I: $66,777
Option: $47,990
Total: $114,767

Items 8 – 21 Including MEMSense Budget and Subcontractor Budget: See Below.

Item 15: Subcontractors:

Dr. David Bevly
Department of Mechanical Engineering
Auburn University
Auburn, AL
36849

MEMSense Budget
Period of Performance: 9/1/07 - 2/28/08

		Burdenned Ra	hours/month	% effort	monthly rate	man-months	Phase I (6 Months)	man-months	Option (4 months)
French, S	DE1	170	160	35	$9,520	1.80	17,136.00	1.70	16,184.00
Gibson, M.	EE1	200	160	25	$8,000	1.00	8,000.00	1.70	13,600.00
Hamm, C.	MM1	200	160	5	$1,600	1.00	1,600.00	0.25	400.00
Rohrbach, R.	EA1	70	160	5	$560	1.00	560.00	0.25	140.00
							27,296.00		30,324.00
TRAVEL & CONFERENCE COSTS:			Phase I	Option					
Travel to Subcontractor: Two Persons, two trips for 4 days each.									
Per Diem for 8 days			314	314					
Airfare to Auburn			1952	1952					
Add. Ground Travel Cost:			100	100					
Total Travel			2366	2366			2,366.00		2,366.00
EQUIPMENT COSTS:			Phase I	Option					
Equipment									
NI PCIe-6259 for DAQ			1200	N/A					
Test Computer			1300	N/A					
Aero cables: x 2			200	N/A					
Other Costs:									
Lab Supplies (Electronic Components, etc.)			100	100					
Total Other Costs			2800	100			2,800.00		100.00
Equipment									
Stock CDG Assembly			3615	N/A					
Development Board			1000	N/A					
Sensors:									
12 x Colibrys Accelerometers			1680	N/A					
12 x Analog Devices ADXL Series Gyros			420	N/A					
GPS			1000	N/A					
Total Equipment			13315	200			13,315.00		200.00
Year 1 Funds							**45,777.00**		**32,990.00**

Bevly Budget
Period of Performance: 9/1/07 - 2/28/08

		FT Mo Rate	% Effort	Phase I (6 Months)	Option (4 months)	
Bevly, D.	P.I.	10,203	46	4,726	4,726	9,453
Dean, R.	Co-PI	8,778	25	2,195		
RA #1	Graduate Student	2,000	50	5,767	3,953	9,720
Benefits (24.5% - Faculty & Staff Only)				1,696	1,158	2,854
TOTAL SALARIES & BENEFITS:				14,384	9,837	24,221
TRAVEL & CONFERENCE COSTS:						
	Trip to Sponsor				437	437
	Total Travel				437	437
OTHER DIRECT COSTS:						
Non-Capital Equipment (<$2,500):						
	PC104 for Data Acquisition					
	Personal Computer					
Other Costs:						
	Lab Supplies (Electronic Components, Sensors, etc.)					
Total Other Costs						
Modified Total Direct Cost (MTDC)				14,384	10,274	24,658
INDIRECT COSTS: (46%)				6,617	4,726	11,343
Capital Equipment (>$2,500)						
	Total Equipment					
Year 1 Funds				**21,000**	**15,000**	36,001

22. On the following items offeror must provide a yes or no answer to each question.

a. Has any executive agency of the United States Government performed any review of your accounts or records in connection with any other government prime contract or subcontract within the past twelve months? If yes, provide the name and address of the reviewing office, name of the individual and telephone extension.
No.

b. Will you require the use of any government property in the performance of this proposal?
No

c. Do you require government contract financing to perform this proposed contract?
Yes.
If yes, then specify type as advanced payments.
Advanced payments.

23. Type of contract proposed: firm-fixed price.

OFFICE
OF SPONSORED
PROGRAMS

AUBURN UNIVERSITY
VICE PRESIDENT FOR RESEARCH

June 8, 2007

Mr. Samuel French
MEMSense, LLC.
2693D Commerce Rd.
Rapid City, SD 57702
Phone: (888) 668-8743
Fax: (413) 674-9793
Email: sfrench@memsense.com

RE: Improved Far-Target Location Accuracy-Army SBIR Program, Topic#A07-085

Dear Mr. French:

Auburn University is pleased to participate as a subawardee under the referenced research project. Total estimated funding from MEMSense, LLC. is $21,000 over a period of six months with an optional 4 months for additional funding of $15,000 for Auburn University's portion of the project.

Dr. David Bevly of the Department of Mechanical Engineering will serve as the principal investigator for Auburn's effort.

We appreciate the opportunity to work with you on this important project. If you have any technical questions regarding this project, please contact Dr. Bevly at (334) 844-3446. Should the proposal be accepted for negotiation, please contact Mr. Gene Taylor, Associate Director, Office of Sponsored Programs, 310 Samford Hall, Auburn University, AL 36849. Mr. Taylor's telephone number is (334) 844-4438; his fax number is (334) 844-5953 and email address is taylol2@auburn.edu. If any additional information is needed, please do not hesitate to contact us.

Sincerely,

Ralph Zee

Ralph Zee, Ph.D
Acting Associate Provost and
Vice President for Research

310 Samford Hall, Auburn, AL 36849-5131; Telephone: 334-844-4438; Fax: 334-844-5953
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