Weapons and Systems Engineering Department

Professor Terrence E. Dwan
Chair

Research within the Weapons and Systems Engineering Department continues to provide the faculty with an opportunity to grow professionally and to keep abreast of rapidly advancing systems technology. In addition, every graduating Systems Engineering major participates in research, design, and development projects for the purpose of realizing practical applications of some of the theory which they have studied.

Every faculty member, both civilian and military, either participates in research in areas of interest to the U.S. Navy or supports midshipmen research programs in an advisory capacity. Faculty research areas currently include fuzzy modeling, magnetic bearings, metrology, robotics, ship power systems, and system identification.

This year there was one Trident Scholar in the Systems Engineering Department. The scholar engaged in an extensive research project in lieu of several courses. The research was the development of a model to address shipboard automation. Strong emphasis continues on the faculty-midshipman relationship during the individual research oriented capstone design course. Each midshipman is assigned both an administrative and a technical adviser. These advisers not only provide support of a technical nature, but also emphasize planning, scheduling, and effective oral and written presentation. Typical examples of midshipmen research projects include development of autonomous carts and boats, automatic target detection, magnetic levitation, and vibration control.

Funding for research continues to be diverse. Sponsors for this year included the Naval Academy Research Council, the Office of Naval Research, the Naval Research Laboratory, the Naval Surface Warfare Center, and the National Institute of Standards and Technology.

Sponsored Research

Using an 8-bit Controller to Achieve Network Capability and Communicate to a 32-bit Personal Computer

Researchers: Associate Professor Svetlana Avramov-Zamurovic and
Associate Professor Carl E. Wick
Sponsor: National Institute of Standards and Technology (NIST),
Information Technology Division

Microcontrollers are widely used in embedded systems and will play a significant role in the emerging field of pervasive computing. A popular microcontroller is Microchip's Technologies' Peripheral Interface Controller (PIC) an 8-bit Harvard-style reduced instruction set (RISC) microcontroller. The top-of-the-line PIC has up to 64 kb of program memory, approximately 400 bytes of data registers and maximum operating frequency is 33 MHz. Most of the instructions are the same length and it takes only 4 clock cycles to process one instruction. This allows PIC to control very fast processes.

The challenge is to explore the possibility of using an 8-bit controller as a bridge between 32-bit network-enabled personal computers (PCs) and existing non-networked appliances such as laboratory instruments, house appliances and office equipment. The goal is to interconnect these appliances with existing networked PCs to achieve one key aspect of pervasive computing.

The immediate task is to develop a means to interconnect PCs and microcontrollers via the standard Internet protocols. The project involves researching existing integrated circuit technology to design such an interface. The main portion of the work

is a study of the TCP/IP protocol and its implementation as it relates to microcontrollers and their use in pervasive computing. The final phase of the project is the design procedure assessment. This analysis addresses issues associated with standardization of microcontroller network integration.

A Framework for Assessing Minimum Communication Requirements for Cooperating Underwater Weapons and Vehicles

Researchers: Assistant Professor Bradley E. Bishop and Assistant Professor Daniel J. Stilwell
Sponsor: Office of Naval Research (ONR)

Limited communications bandwidth is a significant obstacle for decentralized control and coordination of underwater weapons and vehicles, including networks of torpedoes, anti-torpedo torpedoes and autonomous underwater vehicles (AUVs). This project focused on the characterization of *minimum* inter-vehicle communication requirements using a systems-theoretic framework.

The primary tool used for this research was decentralized control. Using methods from this body of work, techniques were developed under which the existence of decentralized controllers can be determined, and communication requirements explicitly evaluated, for platoons of cooperating underwater vehicles.

Additionally, this work motivated investigations into the capabilities of platoons of vehicles. Using techniques from redundant manipulation, a new formalism for platoon-level objectives and control was developed. This is a rich area for new research, and will allow for systematic development of platoon objectives and control techniques for centralized cooperation. Future efforts involve the extension of this effort to decentralized techniques.

Supervisory Control of Learning Multi-agent Systems

Researcher: Assistant Professor Kiriakos Kiriakidis
Sponsor: Naval Research Laboratory (NRL)

Multi-agent architectures are characteristic of composite systems such as a platoon of mini-submersibles or a swarm of micro-air-vehicles. Because the behavioral complexity of multi-agent systems increases with the number of agents, ad hoc solutions that work for groups of few agents are difficult to generalize for large-scale architectures. For systems with fixed structure, the methodology of supervisory control successfully treats the analysis and design of the agents' collective behavior. A more challenging problem, however, arises when the structure of a multi-agent system changes, for example, through learning. Herein, we develop an approach that extends the supervisory control theory to learning multi-agent systems and guarantees the collective behavior within specifications in spite of structural changes.

H-Infinity Control Theoretic Methods for Antennae

Researchers: Assistant Professor Richard T. O'Brien
and Assistant Professor Kiriakos Kiriakidis
Sponsor: Office of Naval Research (ONR)

This project investigates two important problems relevant to antennae applications. The filtering problem involves the estimation of received data from noisy measurements as in radar applications. The control problem involves the regulation of the flow of information to and from an antenna as in communication networks. The dynamics of antenna systems are complex and exact mathematical models are difficult or impossible to obtain from first principles. Most of the existing design methods require an accurate model of the system and are unable to accommodate problems of this type. In this project, these two problems are considered in a very general context and the antennae are modeled as uncertain, nonlinear, time-varying systems. Existence of solutions of both problems will be addressed for an uncertain nonlinear or time-varying model. Design and synthesis procedures for the filtering and control problems will be developed for linear, time-varying systems with potential extensions to the general problem.

Uncalibrated Vision-Guided Mobile Robotic Control

Researcher: Assistant Professor Jenelle L. Piepmeier
Sponsors: Naval Academy Research Council (NARC) and Office of Naval Research (ONR)

This research experimentally demonstrated vision-based mobile robot control using a fixed camera. A commercially available vision system is used to identify the robot position and a moving goal position. With little a priori knowledge, the control method estimates the system model on-line and does not require calibrated camera or mobile robot parameters. The system model is estimated utilizing a recursive nonlinear least squares Jacobian estimation scheme. The robot is controlled by a dynamic quasi-Newton method that utilizes the estimated Jacobian. This type of controller has been previously demonstrated on manipulator robots; this research demonstrates further applications of the method. Results demonstrated the control of two differential drive mobile robots. These robots varied in size, accuracy, and the types of control commands they were designed to accept. The use of the same controller to command two very different robots to follow a target identified by the vision system highlights the flexibility of this approach. This combination of system estimation and control is being developed for mobile robot navigation and obstacle avoidance.

Anomaly Analysis of the Hubble Space Telescope's Attitude Control System Zero-Gyro Sun-Point Mode

Researcher: Associate Professor George E. Piper
Sponsor: NASA/Goddard Space Flight Center

The Hubble Space Telescope's Zero-Gyro Sun-Point (ZGSP) is a safemode that maintains the spacecraft in a solar orientation to ensure a power-positive and thermally safe state without the use of rate gyros. Following the loss of a rate gyro in November 1999, HST entered ZGSP safemode. While in ZGSP safemode, the spacecraft experienced occasional large deviations from the desired solar orientation. The objective of this study was to evaluate recommended fixes and improvements to ZGSP. Based on On-orbit data, simulations and analysis, areas for improvement in ZGSP have been identified. Potential improvements have been listed and some of these have been implemented and assessed.

MIMO Stability Analysis of the MAP Attitude Control System

Researcher: Associate Professor George E. Piper
Sponsor: NASA/Goddard Space Flight Center

The Microwave Anisotropy Probe (MAP) is part of NASA's Explorer Program to study conditions in the early universe. MAP will measure the temperature differences ("anisotropy") in the cosmic microwave background radiation. MAP is scheduled to launch in the spring of 2001 and will be placed in a Lissajous orbit around the Earth-Sun L2 Lagrange point to suppress potential instrument disturbances. MAP will make interconnected measurements over a large area of the celestial sphere by executing a combination fast spin and slow precession of the spacecraft's spin axis. The MAP ACS will implement this observing mode spin-scan in addition to providing for orbit maneuvers and safehold contingencies.

This project investigated the multiple-input multiple-output (MIMO) stability of the MAP attitude control system (ACS). Earlier analyses used single axis approximations to examine the ACS stability and performance. In an effort to increase the confidence level for mission success, the current work investigates the effects of three-axis coupling due to internal momentum, flex dynamics, and products of inertia.

Cooperative Control for Platoons of Autonomous Underwater Vehicles

Researcher: Assistant Professor Daniel J. Stilwell
Sponsor: Office of Naval Research (ONR)

This project involved development of theoretically justified approaches of controlling platoons of autonomous underwater vehicles, with an emphasis on limited communication bandwidth.

Development of a Miniature Autonomous Underwater Vehicle and Evaluation of Guidance Systems

Researchers: Assistant Professor Daniel J. Stilwell and Associate Professor Carl E. Wick
Sponsor: Northrop Grumman Corporation

A miniature autonomous underwater vehicle was constructed to explore the feasibility of, and to determine technical issues that are associated with low-cost autonomous vehicles for a variety of shallow underwater military and non-military missions. The design of this vehicle evolved from a Northrop Grumman concept in which miniature vehicles would be used to locate and tag underwater mines in a minefield. This work resulted in the construction of a miniature prototype autonomous vehicle approximately 23 in. in length and 3.5 in. in diameter. Sensors on the vehicle allowed for autonomous dead-reckoning navigation; these included a water pressure sensor, an electronic compass, twin accelerometers and a rate gyro. Navigation accuracy of these low-cost sensors was evaluated and methods were determined that would increase the overall navigation accuracy of the system as a whole. Follow-on work will result in the construction of a next-generation miniature vehicle.

Magnetically Suspended Actively Reduced Dynamic Imbalance Wheel

Researcher: Associate Professor John M. Watkins
Sponsor: NASA-ASEE Summer Faculty Fellowship Program (SFFP)

The primary goal of this project was a Magnetically Suspended Actively Reduced Dynamic Imbalance Wheel (MASAREDI). Gary Brown of the Electromechanical Systems Branch at the NASA/Goddard Space Flight Center was my research associate. To meet the stringent pointing requirements of future precision missions such as the Next Generation Space Telescope (NGST), spacecraft designers must reduce component vibrations. The goal of this project is to develop a magnetically suspended momentum wheel capable of actively reducing imbalance vibrations by an order of magnitude of existing ball bearing designs.

The momentum/reaction wheel has 5 degrees of freedom of active control consisting of 2 radial degrees of freedom at the top of the shaft, 2 radial degrees of freedom at the bottom of the shaft, and 1 axial degree of freedom. Typically, this would require two radial magnetic bearings and one axial bearing. In this system, however, the radial and axial functions were combined into a single design for a more compact and elegant package.

My primary contributions to this project were in the areas of dynamic system modeling and control system design. While we did achieve some success in the control of the magnetic bearings, analysis, simulation and experimental results showed that the power electronics used to drive the magnetic bearings were inadequate for the size of this system. Currently, the power electronics are being redesigned and more fidelity is being added to the dynamic system model and simulation to improve our analysis and design capabilities.

Yard Patrol (YP) Craft Automation Demonstration

Researcher: Assistant Professor Edwin L. Zivi
Sponsor: Office of Naval Research (ONR)

The Naval Research Advisory Committee[1,2] has called for robust demonstrations of automation for reduced manning. In response, YP-679 has been transferred from USNA to ONR ownership as a dedicated automation technology demonstration platform. Successful demonstrations of fault tolerant control for propulsion, auxiliaries, and steering were performed during the summer and fall of 2000. These tests established the feasibility of enhancing commercial automation technology with network fragment healing to obtain cost effective, survivable control for mission critical shipboard systems. The network fragment healing of ANSI-709.1 LonTalk networks has been pioneered by team member Adept Systems. Anteon Inc. provided control system engineering and integration with support from the USNA Small Craft Repair Facility. The Naval Surface Warfare Center provided machinery control, software development, and graphical user interface support. Following a successful underway demonstration to the Chief of Naval Research, YP-679 has acquired a broader role as an ONR technology demonstration craft.

[1]Naval Research Advisory Committee, Reduced Ship Manning, Office of Assistant Secretary of the Navy for RD&E, November 1995.

[2]Naval Research Advisory Committee, Damage Control and Maintenance (for Reduced Manning), Office of Assistant Secretary of the Navy for RD&E, August 26, 1996.

Control of a Survivable Integrated Power System

Researcher: Assistant Professor Edwin L. Zivi
Sponsor: Naval Sea Systems Command (NAVSEA)

The NAVSEA Integrated Power System development and companion Office of Naval Research Electric Warship initiative provide rich opportunities to modernize naval warfare. As a result of mandated crew size reductions, integrated power generation, distribution, propulsion, and weapons systems must be highly automated. These systems must continuously support the tactical mission with minimal human intervention. Integrated Power System survivability and reliability requirements are a direct result of the transfer of casualty response duties from manpower intensive engineering and damage control teams to automation. To replace human senses and muscle, an automated power system must provide continuous power and situational awareness.

Under combat conditions, battle damage is a reality. The tempo and lethality of modern warfare requires a robust warship that "fights through" battle damage. To provide this capability, an Integrated Power System is required to provide power continuity to vital combat and damage control systems. The Integrated Power System must function continuously despite major disruptions in both the power system and the associated automation. This disruption is not a discrete event; rather it evolves and expands with time. Throughout the damage progression, the automation must effectively sequence an effective casualty recovery. The close spatial and temporal clustering of combat casualty events and concurrent damage to both the power system and the automation, severely challenge conventional fault masking and fault recovery procedures. This research is being performed in association with the Energy Systems Analysis Consortium. Power survivability will be achieved by unifying advances in fault containment, analytic redundancy, component level intelligence, network fragment healing, and non-linear stabilizing control.

Independent Research

Noise Reduction in High Range Resolution Radar (HRR) Signatures for Automatic Target Recognition

Researcher: Major Randy P. Broussard, USAF

Independent research to remove noise from HRR signatures of aircraft using wavelets, interaction between filtered signatures and Gaussian classifiers are optimized for maximum identification percentage and minimum false alarms. Filtering is nonlinear and computer optimization techniques are used to find optimal nonlinear settings.

Wavelet Pre-Processing for High Range Resolution Radar (HRR) Classification

Researcher: Major Randy P. Broussard, USAF

Independent research to develop a wavelet denoising scheme to aid an Automatic Target Recognition (ATR) system in recognizing aircraft from High Range Resolution Radar (HRR) signatures. A template matching classification technique is used with templates formed from synthetically generated signatures. The goal of the classification system is to achieve classification accuracy equivalent to that obtained with measured HRR signatures. Results suggest that a large portion of HRR signature content is non-discriminatory. The wavelet denoising process removes the non-discriminatory information, thereby leading to remarkable increases in classification accuracy. Results are shown for HRR signatures from six aircraft.

Basic Utility Rover for Research Operations

Researcher: LT Paul J. Frontera, USN

Technology is advancing such that, in the not-too-distant future, Mars will be open to human exploration. A robotic field assistant would improve an astronaut's ability to conduct surface exploration. This paper describes the Basic Utility Rover for Research Operations (BURRO), a 625 kg rover to provide such aid. The rover was designed to meet specified given requirements while operating in the known conditions of the Martian environment. The system is able to: (1) drive over a 0.5 m obstacle; (2) carry a 200 kg astronaut, robot arms weighing 150 kg, and 100 kg of mission-specific payload; (3) carry a second astronaut in case of emergency; (4) maintain a 5 km/h speed through the duration of an eight hour traverse; (5) sustain a 10 km/h sprint for one hour; (6) be directly driven by an on-board astronaut, teleoperated, or operated in semi-autonomous or fully autonomous modes; (7) traverse up or down a 30º slope or perpendicular to a 20º slope; and (8) park parallel to a 45º slope or perpendicular to a 30º slope.

Steering Control of an Articulated Vehicle Using Differential Braking

Researchers: Assistant Professor Richard T. O'Brien
and Associate Professor George E. Piper

The need to accommodate increased vehicular traffic in existing highway space has motivated research on intelligent transportation systems. In particular, automated highway systems (AHS) have been proposed as an alternative to the construction of new highways. Primarily, AHS research has focused on the automation of passenger vehicles. More recently, automation of articulated vehicles (i.e., tractor-trailers) has been considered. The benefits of these systems would be safer, less congested highways. The drawback is that an extensive infrastructure is required to implement such a system.

In the absence of AHS, individual vehicle automation items such as speed-sensitive steering, traction control, tire pressure monitoring systems, and sensor-based "virtual bumpers" have been developed to enhance the driver's ability to control the vehicle. These improvements are localized to the vehicle and do not require the infrastructure of AHS. The aim of this paper is discuss localized automation for articulated vehicles.

In this project, the design of a steering controller for the trailer of an articulated vehicle using differential braking was investigated. The control objective is to regulate the relative angle between the tractor and trailer to a desired angle determined by the road curvature and speed of the vehicle. Assuming a constant speed, a linear, time-invariant model was developed and the control system was designed using H_∞ methods.

There was a conflict between the assumption of constant velocity and the use of differential braking for steering control. The braking force required for control slowed the vehicle significantly. In the future, a more realistic scenario will be considered where the vehicle is already braking and the differential braking force is superimposed to steer the trailer of the articulated vehicle.

Poles of Linear, Time-Varying Systems

Researcher: Assistant Professor Richard T. O'Brien

The importance of poles and zeros in controller design for time-invariant systems is well known. In particular, the location of the poles and zeros of a single-input, single-output , linear, time-invariant system determines the achievable performance and robustness in the closed-loop system. In this project, a suitable definition for the poles of a linear, time-varying system is sought for use in the analysis and design of controllers for linear, time-varying systems.

An analogous definition of poles for continuous-time, linear, time-varying systems has been developed. A pole set for a time-varying state equation defines a stability-preserving variable change relating the original state equation to a time-varying, upper triangular state equation. This transformation is analogous to the Schur decomposition of a constant matrix. This defini-

tion has been shown to be a generalization of the definition in the time-invariant case and to be consistent with existing results for linear, time-varying systems. There are several differences from the time-invariant case. The poles are functions of time and the poles are defined in a set, not individually. Furthermore, a pole set of a time-varying system is not unique. However, it has been shown that any pole set contains complete information about the stability of the state equation and the behavior of its solution. Furthermore, the pole set and the variable change can be computed using a QR decomposition of the transition matrix for the state equation.

Currently, two issues associated with the poles of linear, time-varying system are being investigated. The first issue is that the poles in a pole set are ordered and it is unclear when and/or if the poles are to be interchanged. The second issue has to do with the connection between the poles and the frequency response of a linear, time-varying system. From the linear, time-invariant case, it seems reasonable that there must be a connection; but just how the time-variation in the poles affect the system's frequency response is an issue to be investigated.

Distributed Power System Simulation

Researcher: Assistant Professor Edwin L. Zivi

Complex, interactive systems such as the Navy's Integrated Power System require a suite of modular, simulation and control system design tools. Shipboard finite inertia power systems are numerically stiff with eigenvalues in the range of –0.1 to -1×10^{-10} requiring a variety of modular, numerically efficient, simulation and control system design tools. Power quality, signature, and electro-magnetic interference studies require detailed, waveform level analysis. Meanwhile, system transient and stability studies require reduced order models which retain the essential nonlinear and variable structure attributes of detailed, waveform level models. Moreover, control system design algorithms require simplified, continuous models which are typically linearized. USN Integrated Power System experience indicates that numerical performance, modularity, and the availability of realistic models continue to constrain the development of complex, interactive system simulations.

In collaboration with P.C. Krause and Associates, a heterogeneous, distributed simulation research facility will be installed at the Naval Academy. This simulation facility will be composed of low cost, high performance micro/multiprocessors connected by an ANSI/IEEE 1596-1992 Scalable Coherent Interface. This facility will investigate stabilizing control for non-linear, variable structure, integrated power systems, subjected to large scale, combat induced disturbances. Nonlinear average value models, automated state generation, and automated model reduction will be investigated.

Dynamic System Animation Within a Simulink Laboratory Environment

Researchers: Assistant Professor Edwin L. Zivi
and Assistant Professor Jenelle A. Piepmeier

Recent innovations in the animation of student developed, laboratory simulations have been found to significantly improve student understanding and enthusiasm. This animation can be implemented using Matlab s-functions that are typically called from a Simulink simulation. These rudimentary animations have been found to be relatively easy to construct and well received by students. To date, animations have been developed solely as part of faculty course preparation. Ongoing investigations aim to continue to streamline the Matlab/Simulink interface and increase the visual effectiveness of real-time animation. The goal is to develop a richer set of run-time displays and indicators without jeopardizing the simplicity or portability of existing tools.

Research Course Projects

Fundamental Principles and Calibration of a Mid-grade Inertial Measurement Unit

Researcher: Midshipman 1/C David J. Campbell, USN
Adviser: Assistant Professor Daniel J. Stilwell

The basic principles of calibration and alignment of an inertial measurement unit, with special attention to the requirements of autonomous underwater vehicles, was investigated. A paper on this work is to be published at the Underwater Untethered Technology Symposium in the summer of 2001.

Survivable Control Algorithms for the Integrated Power System

Researcher: Midshipman 2/C Daniel F. Chiafair, USN
Adviser: Assistant Professor Edwin L. Zivi

Today's warships are constructed with segregated mechanical propulsion and electric power systems. In current ships, the power dedicated to ship propulsion is about 90% of the total ship power and power dedicated to electrical generation is about 10%. The existing ship service electrical system is not very robust: because the system is very tightly coupled, a single casualty can disrupt the entire system causing a total loss of electrical power. Even though the mechanical propulsion system may be in perfect working condition, it cannot provide any electrical power to the ship. Incremental improvements have been implemented on DDG-51 Flight IIA. The new strike destroyer, DD-21, will have a fundamentally new system.

To improve combat effectiveness and survivability, an Integrated Power System will be deployed on DD-21 and other future naval combatants. The key advantage of an electronically controlled, Integrated Power System is the ability to actively control the flow of power throughout the distribution system. Robust, control algorithms are required to maintain power and, if necessary, re-route power to critical systems. This research builds on existing fault tolerant power system control strategies to derive new control algorithms for improved Integrated Power System survivability.

Supervision of a Platoon of Robots

Researcher: Midshipman 1/C Luis R. Henriquez, USN
Adviser: Assistant Professor Kiriakos Kiriakidis
Sponsor: Naval Research Laboratory (NRL)

This research consists of working with small robots and trying to find a way in which they can communicate effectively. The idea is to have a robot supervisor who gives orders to the other robots and makes his own decisions based on information gathered from the other robots. To do the testing of the idea we are using the Lego Mindstorms robots, which are very simple and yet have the capabilities of sensing their surroundings. RCX is the name of the Lego block that can be programmed and which may have sensors and actuators connected to it. They can use touch, light, heat, and even rotation sensors. They are also equipped with an infrared port, through which they are programmed to do the numerous tasks and through which they can also communicate with other robots. Finite State Machine or Automata (FSM/FSA) theory has been used in order to simulate the system. This theory provides for a design where the robots will execute only the action that they are supposed to by being disabled from executing any other action. Communication between robots is crucial, for the developed method requires sending binary messages. Each message contains several information bits, in which orders and addresses of the transmitting and receiving robot are encoded.

Automated Underway Replenishment

Researcher: Midshipman 1/C Nikolaus T. Keapproth, USN
Adviser: Assistant Professor Richard T. O'Brien

This project used methods learned in ES202, 301, 302, 307, 308, 401 courses, and in the controls, communications, and computers engineering tracks within the Systems Engineering major to automate the underway replenishment process. One model boat is controlled entirely from shore by radio control, and the other boat locates the first boat, drives towards it, and pulls up alongside it. It then maintains exact position abeam, following the R/C boat's course and speed changes.

Currently, prototypes of the required sensors have been built and tested. Furthermore, the boats have been equipped with motors to turn the screws. In the fall, a group of students will continue this project with the goal of testing and refining the system on the water.

Hardware-in-the-Loop Simulation for Autonomous Rendezvous and Capture Systems

Researcher: Midshipman 1/C Stephen M. Long, USN
Advisers: Associate Professor George E. Piper
and Assistant Professor Bradley E. Bishop

This project focused on the development of simulation and hardware tools for a hardware-in-the-loop simulation study of satellite control, specifically autonomous rendezvous and capture (ARC) systems.

The primary objectives of this research were to develop a real-time simulation for spacecraft dynamics and control systems for ARC, and to couple those simulations with actual hardware. The hardware platform used to simulate the satellite network was a pair of 5 degree-of-freedom SCORBOT ER-V Plus industrial robotic arms. The satellites were models placed in the gripper of each of the robots. Feedback for the control was generated using a CCD camera (attached to one of the satellite models) and a Data Translation DT-55 framegrabber card in the host PC.

The overall project used actual feedback from the camera/robot system as input to the simulated spacecraft. The simulator provided motion commands for the robotic arms, which followed the trajectories such that the satellite models moved exactly as would spacecraft with the same visual feedback and orbital state (which was simulated). With the hardware platform and simulation in place, work continues on the evaluation of various control strategies for ARC.

Control of a Double Integrator Using Position Feedback Only

Researcher: Midshipman 2/C Michael G. Vasek, USN
Adviser: Assistant Professor Richard T. O'Brien

The main focus of this project is to investigate the practical implementation of a control system that controls the position of a double integrator system using only feedback control. An application of this research is an automated steering control of a vehicle. The double integration is only a conceptual building block for this type of a system. In a true system analysis the dynamics of the system need to be added to the analysis.

The concept has been verified using computer simulation, and the project will continue in the fall with the goal of developing a desktop experimental apparatus to demonstrate the concept. This concept will be then be extended to an automated vehicle in the spring semester.

Midshipman Design Projects

Formation Control for a Team of Mobile Robots
Researchers: Midshipmen 1/C David W. Ayotte, Jeremy L. Kim and Jeffrey S. Mitchell, USN
Advisers: Assistant Professor Bradley E. Bishop
and Lieutenant Commander Charles B. Lynch, USN

Systems Ball
Researchers: Midshipmen 1/C David M. Bader, David J. Hess and Adam K. Kuehne, USN
Advisers: Professor Terrence E. Dwan and Major Randy P. Broussard, USAF

Web Satellite
Researchers: Midshipmen 1/C Vytenis Benetis and Ryan G. Vest, USN
Advisers: Associate Professor Svetlana Avramov-Zamurovic and
Lieutenant Commander Michael J. Clayton, USN

Night Rider
Researchers: Midshipmen 1/C Lawrence Brandon and Luis R. Henriquez, USN
Advisers: Assistant Professor Richard T. O'Brien and Major Darin J. McCloy, USMC

Automated Underwater Vehicle (AUV)
Researchers: Midshipmen 1/C William F. Bundy, David J. Campbell, Emily A. Markel,
William T. Rimmer, Mark C. Risser and Patrick A. Salmon, USN
Advisers: Assistant Professor Daniel J. Stilwell
and Lieutenant Commander Frederic D. Forney, USN

Automobile Safety HUD
Researchers: Midshipmen 1/C Michael D. Cataffo and John R. Wilkinson, USN
Advisers: Professor Thomas E. Bechert and Lieutenant Commander Michael J. Clayton, USN

Double Inverted Pendulum
Researchers: Midshipman 1/C Douglas S. Chase and Ricardo Rivera, USN
Advisers: Assistant Professor Daniel J. Stilwell
and Lieutenant Commander Frederic D. Forney, USN

Multiple Mobile Cooperative Autonomous Robots
Researchers: Midshipmen 1/C Bennett M. Christman, Philip B. Keith
and William B. Wolf, USN
Advisers: Associate Professor Carl E. Wick and Commander Juan A. Navarrete, USN

Autonomous Maze
Researchers: Midshipmen 1/C Gale A. Clark, Landon L. Jones and Jared P. Sobczak, USN
Advisers: Assistant Professor Bradley E. Bishop and Commander James W. Trueblood, USN

Active Magnetic Bearing
Researchers: Midshipmen 1/C Cameron D. Collier, Andrew B. Nozik and Jason E. Sohlke, USN
Advisers: Associate Professor George E. Piper, Associate Professor John M. Watkins
and Lieutenant Commander Brian S. Tait, USN

Voice Activated Trap Shoot
Researchers: Midshipmen 1/C James P. Conklin and Scott M. Dalziel, USN
Advisers: Visiting Professor Robert H. Small and Major Darin J. McCloy, USMC

Systems Ball
Researchers: Midshipmen 1/C Tiko S. Crofoot, Benjamin F. Harrison and Matthew R. Lovitt, USN
Advisers: Professor Terrence E. Dwan and Major Darin J. McCloy, USMC

Weight Assisting Robot
Researchers: Midshipmen 1/C Blake A. Crosby and John R. Wilkinson, USN
Advisers: Professor Thomas E. Bechert and Commander James W. Trueblood, USN

Systems Ball
Researchers: Midshipmen 1/C William E. Culpepper and Theodore F. Olson, USN
Advisers: Assistant Professor Kiriakos Kiriakidis and Commander David T. Bailey, USN

Robo-Umpire
Researchers: Midshipmen 1/C Ryan C. Dewitt and Matthew L. Zarracina, USN
Advisers: Assistant Professor Jenelle A. Piepmeier and Commander Rodney M. Adams, USNR

Web-Based Interface with Mobile Robot
Researcher: Midshipman 1/C Patricia E. Dixon, USN
Advisers: Assistant Professor Jenelle A. Piepmeier and Commander Rodney M. Adams, USNR

Autonomous Miniature Golf
Researchers: Midshipmen 1/C Tomasz Dmitrukowski and John P. Dunn, USN
Advisers: Professor Kenneth A. Knowles and Commander Jay A. Gutzler, USNR

Office Messenger Robot
Researchers: Midshipmen 1/C Daniel I. Doyle and Rubin E. Marin, USN
Advisers: Assistant Professor Bradley E. Bishop, Associate Professor Carl E. Wick and Commander David T. Bailey, USN

Active Magnetic Levitation Demonstrator
Researchers: Midshipmen 1/C Tim W. Farward and Michael W. Paulus, USN
Advisers: Associate Professor George E. Piper, Associate Professor John M. Watkins and Lieutenant Commander Brian S. Tait, USN

Autonomous Sailboat
Researchers: Midshipmen 1/C David W. Fassel and Adam T. Nelson, USN
Advisers: Assistant Professor Edwin L. Zivi and Commander Juan A. Navarrete, USN

Autonomous Boat Design
Researchers: Midshipmen 1/C Darija Gvozdencevic, Christopher M. Kelmis, Bryant A. Nunn and Charles W. Rowland, USN
Advisers: Associate Professor George E. Piper and Lieutenant Commander Craig M. Payne, USNR

Smart Fire Sprinkler
Researchers: Midshipmen 1/C Samuel H. Hallock and Joseph B. Mitzen, USN
Advisers: Visiting Professor Robert H. Small
and Lieutenant Commander Craig M. Payne, USNR

Firefighting Robot
Researchers: Midshipmen 1/C Clayton N. Hergert and Erick Min, USN
Advisers: Assistant Professor Bradley E. Bishop, Professor Kenneth A. Knowles
and Commander Bradley D. Taylor, USNR

Automated Welder
Researchers: Midshipmen 1/C Erich L. Jurges and Tracy L. Ritzman, USN
Advisers: Assistant Professor Bradley E. Bishop, Assistant Professor Jenelle A. Piepmeier
and Major Randy P. Broussard, USAF

Autonomous Free-Fire Robot
Researchers: Midshipmen 1/C Matthew B. Kave, Victor T. Taylor and
Alton L. Washington, USN
Advisers: Associate Professor Carl E. Wick and Lieutenant Robert C. Bandy, USN

Automated Underway Replenishment
Researcher: Midshipman 1/C Nickolaus T. Keapproth, USN
Advisers: Assistant Professor Richard T. O'Brien and Commander Juan A. Navarrete, USN

The Companion
Researchers: Midshipmen 1/C Dianna M. Kulik and James W. Steffen, USN
Advisers: Professor Robert DeMoyer and Lieutenant Commander Charles B. Lynch, USN

Spacecraft Dynamic Motion Simulator
Researcher: Midshipman 1/C Stephen M. Long, USN
Advisers: Associate Professor George E. Piper and Commander James W. Trueblood, USN

Maze of Doom
Researchers: Midshipmen 1/C Taeko E. McFadden and Jennifer L. Sullentrop, USN
Advisers: Assistant Professor Bradley E. Bishop and Commander Jay A. Gutzler, USNR

Windows for Retards
Researchers: Midshipmen 1/C Matthew A. McKenna and Jacob F. Wingebach, USN
Advisers: Assistant Professor Kiriakos Kiriakidis and Commander Bradley D. Taylor, USNR

Robotic Firefighter
Researchers: Midshipmen 1/C Andrew P. Mierisch, Michael J. Schroeder
and Scott T. Vane, USN
Advisers: Assistant Professor Bradley E. Bishop, Associate Professor John M. Watkins and
Commander Rodney M. Adams, USNR

Autonomous Bar
Researchers: Midshipmen 1/C Stephen C. Monroe and John L. Roach, USN
Advisers: Associate Professor Svetlana Avramov-Zamurovic
and Lieutenant Commander Nicholas F. Budd, USN

The Automated Cruiser

Researchers: Midshipmen 1/C Ryan A. Mortimer, Zorko Petrusa, Joshua D. Smith and Scott C. Sloan, USN
Advisers: Assistant Professor Richard T. O'Brien and Commander David T. Bailey, USN

Autonomous Amphibious Rover

Researchers: Midshipmen 1/C Michael T. O'Reilly, Wesley A. Turbeville and John G. Vardaman, USN
Advisers: Assistant Professor Daniel J. Stilwell and Lieutenant Commander Mark M. Murray, USNR

Systems Ball

Researcher: Midshipman 1/C Preston M. Rackauskas, USN
Advisers: Professor Kenneth A. Knowles and Lieutenant Commander Nicholas F. Budd, USN

Beam Robots

Researchers: Midshipmen 1/C Colin A. Price and Nathaniel R. Velcio, USN
Advisers: Assistant Professor Bradley E. Bishop and Lieutenant Commander Brian S. Tait, USN

Robotic Snake

Researchers: Midshipmen 1/C Eugene R. Smith and Chad K. Upright, USN
Advisers: Assistant Professor Bradley E. Bishop and Commander Jay A. Gutzler, USNR

Digital Automatic Transmission for a Bicycle

Researchers: Midshipmen 1/C Thomas M. Spahn and Lawrence L. Williams, USN
Advisers: Associate Professor Svetlana Avramov-Zamurovic and Lieutenant Commander Mark M. Murray, USNR

Advanced Shipboard Control Systems

Researcher: Midshipman 1/C Jonathan J. Vanecko, USN
Advisers: Assistant Professor Edwin L. Zivi and Commander Bradley D. Taylor, USNR

Trident Scholar Project

Advanced Shipboard Control Systems

Researcher: Midshipman 1/C Jonathan J. Vanecko, USN
Advisers: Assistant Professor Edwin L. Zivi and Commander Bradley D. Taylor, USNR

For the new millennium, the U.S. Navy has made a fundamental commitment to drastically reduce crew sizes. To obtain significant crew size reductions, automation must be continuously available and dependable under all conditions, including combat battle damage. To continue to work during the worst casualty conditions, command and control networks must automatically reconfigure around battle damage. By autonomously routing data around damaged components in an intelligent manner, network fragment healing dramatically improves distributed control system survivability. Dynamic reconfiguration, using network fragment healing, can provide the continuity of communications service that is required aboard U.S. Naval vessels during combat operations.

To achieve survivable, distributed communication, an industry proven networking standard, ANSI-709.1 Lon-Works, was extended to military applications. Specifically, the topology of a semi-mesh connection of rings, developed by Adept Systems Inc., was investigated through an availability analysis. Using Monte Carlo analysis, hypercube topologies were found to be superior to semi-mesh configurations for complex networks. Enhanced network fragment healing algorithms were also investigated.

Publications

Journal (Refereed) Manuscripts

BISHOP, Bradley E., Assistant Professor, "Design of a Cooperative Autonomous Mobile Robot System at the Undergraduate Level," *ASEE Computers in Education Journal*, Vol XI, No. 2, pp. 44-49, April-June 2001.

This paper describes an undergraduate-level design project in a course on autonomous mobile robot systems. The project is intended to allow a great deal of latitude in implementation and to promote teamwork and integrated design methodologies in a framework that is both instructional and interesting. The technical challenges of the project include limited bandwidth communications, cooperative multi-agent algorithms, data storage and transmission and physical system design/control. Additionally, the project is structured in such a way as to provide the students experience in organizing large teams of cooperative designers and working with small task-dedicated design teams. This design project was a subcomponent of a course in Autonomous Robot Design in the Systems Engineering Department at the United States Naval Academy.

DeMOYER, Robert, Professor, "Interactive Continuous and Discrete Step Response Using MATLAB GUI's," *ASEE Computers in Education Journal*, Vol. XI, No. 1, pp. 58-63.

It is important in the study of classical feedback control to understand the correspondence between pole locations and time response. Quadratic poles are particularly important because many systems can be approximately characterized by a quadratic. This paper describes a program, written in MATLAB and using the Graphical User Interface (GUI), which permits the user to drag a quadratic pole in the s-plane and observe, in real time, the changing continuous step response. The program provides the student with the means to actually observe concepts presented in class, including s-plane lines of constant overshoot, time to peak, and settling time.

A second program is described which allows the student to drag a quadratic pole in the z-plane and to observe the corresponding discrete step response. In addition to overshoot, time to peak, and settling time, the number of samples per cycle are easily seen as the z-pole is moved. The sample time can be changed while the program is in execution. Before describing these programs, the paper discusses aspects of GUI program development.

KIRIAKIDIS, Kiriakos, Assistant Professor, "Robust Stabilization of the Takagi-Sugeno Fuzzy Model via Bilinear Matrix Inequalities," *IEEE Transactions on Fuzzy Systems*, Vol. 9, No. 2, pp. 269-277.

Quadratic stability has enabled, mainly via the linear matrix inequality framework, the analysis and design of a nonlinear control system from the local matrices of the system's Takagi-Sugeno fuzzy model. It is well-known, however, that there exist stable differential inclusions hence Takagi-Sugeno fuzzy models whose stability is unprovable by a globally quadratic Lyapunov function. At present, literature in the broader area of stability analysis suggests piecewise-quadratic stability as a means to avoid such conservatism. This paper generalizes the idea and proposes a framework that supports less conservative sufficient conditions for the stability of the Takagi-Sugeno model by using piecewise-quadratic generalized Lyapunov functions. The advocated approach results in the formulation of the controller synthesis, which, herein, aims for robust stabilization, as a problem of bilinear rather than linear matrix inequalities. A simulation example, which includes an algorithm for solution of bilinear matrix inequalities, demonstrates the proposed method.

O'BRIEN Jr., Richard T., Assistant Professor, and Iglesias, Pablo A., "On the Poles and Zeros of Linear, Time-Varying Systems," *IEEE Journal on Circuits and Systems I: Fundamental Theory and Applications*, 48(5), May 2001, pp. 565-577.

Definition of poles and zeros are presented for continuous-time, linear, time-varying systems. For a linear, time-varying state equation, a set of time-varying poles defines a stability-preserving variable change relating the original state equation to an upper triangular state equation. A zero is a function of time corresponding to an exponential input whose transmission to the output is blocked. Both definitions are shown to be generalizations of existing definitions of poles and zeros for linear, time-varying systems and are consistent with the definitions for linear, time-invariant systems. A computation procedure is presented using a QR decomposition of the transition matrix for the state equation. A numerical example is given to illustrate this procedure.

PIPER, George E., Associate Professor, WATKINS, John M., Associate Professor, O'BRIEN, Richard T., Assistant Professor, and Baumann, David, "Global Control of Fan Noise Using Magnetic Bearings," *ASME Journal of Vibration and Acoustics*, February 2001.

In this paper, a novel approach is presented to reduce fan related noise in an acoustic duct. By using magnetic bearings as an noise control actuator, it is possible to co-locate the anti-noise source with the disturbance noise source. This approach allows for global noise reduction through out the duct system. Using H-infinity control theory, an active noise controller is designed that attains broadband as well as tonal noise reduction at all points along the duct. H-infinity control designs are particularly robust to uncertainties in the plant model. Finally, simulation results demonstrate the global nature of this novel active noise control approach.

STILWELL, Daniel J., Assistant Professor and Lawrence, Douglas A., "On Sampled-Data Implementation of Continuous-Time Gain Scheduled Controllers," *International Journal of Robust and Nonlinear Control*. (invited contribution)

A continuous-time gain-scheduled controller must be transformed to a corresponding discrete-time controller for sampled-data implementation. We show that certain linearization properties of a continuous-time gain scheduled controller are inherited by its sampled-data implementation. We also show that a similar relationship exists for multi-rate gain scheduled controllers arising in flight control applications.

STILWELL, Daniel J., Assistant Professor, "State-Space Interpolation for a Gain Scheduled Autopilot," *AIAA Journal of Guidance, Control, and Dynamics*, Vol. 24, No. 3, 2001.

A procedure for interpolating state-space linear time-invariant controllers for the synthesis of gain scheduled controllers is introduced. The interpolation method is based on state-space Youla parameterization and generates a gain scheduled controller that is locally stabilizing at every operating point of a nonlinear plant. The interpolation method also provides guidance on the selection of operating points at which linear time-invariant controllers should be designed. A gain scheduled autopilot is designed to illustrate the interpolation method.

WATKINS, John M., Associate Professor, and MITCHELL, E. Eugene, Professor, "A MATLAB Graphical User Interface for Interactive Design of Linear Quadratic Regulators," *Computers in Education Journal*, Vol. VXI, NO. 1, pp. 53-57, 2001.

The optimal Linear Quadratic Regulator (LQR) method is a powerful technique for designing controllers for complex systems that have stringent performance requirements. For most realistic applications, the LQR problem must be solved via a Computer-Aided-Design (CAD) package such as MATLAB. With the CAD packages solving the optimization problems, the challenge lies in how the weighting matrices are chosen. With experience, practicing engineers become quite adept at choosing these matrices for a specific application. Students in a typical quarter or semester long course do not have the luxury of this experience. Consequently, the authors of this paper have written a MATLAB Graphical User Interface (GUI) that allows the students to easily "tune" the weighting

matrices and immediately see the consequences of those changes. This paper describes the motivation behind the LQR Design GUI, the GUI construction process, and the use of the LQR Design GUI in the senior-level modern control systems course at the U.S. Naval Academy.

Conference Proceedings

AVRAMOV-ZAMUROVIC, Svetlana, Associate Professor, Kinard, Joseph R., and Lipe, Thomas E., "A New Binary Inductive Divider Comparator System for Measuring High-Voltage Thermal Converters," *IMTC 2001 Proceedings*, Budapest, India, May 2001, (CD-ROM).

National Measurement Institutes have traditionally used bootstrapping or build-up techniques to determine the ac-dc difference of high-voltage thermal (HVTCs) converters in terms of the ac-dc difference of lower-voltage converters. We describe a method of determining the ac-dc difference of HVTCs which is independent of the build-up process. A description of the system and technique is given, and preliminary data presented.

AVRAMOV-ZAMUROVIC, Svetlana, Associate Professor, WICK, Carl E., Associate Professor and DEMOYER, Robert, Professor, "Metrology Experiment for Engineering Students: Platinum Resistance Temperature Detector," *Proceedings of the 2000 ASEE Annual Conference*, St. Louis, MO, June 2000, (CD-ROM).

This paper describes the use of a platinum resistance temperature detector to develop a calibration experiment and to introduce metrology principles. The Callender-Van Dusen equation is used to analyze the temperature-resistance characteristic of a detector. Linearity of this characteristic is explored using a MATLAB simulation. Resistance is measured at four different temperatures to estimate all of the parameters in Callender-Van Dusen equation. Since the uncertainty of temperature and resistance measurements during calibration determines the accuracy of the temperature measurements using platinum detector, it is necessary to assess the calibration errors. A simulation package is developed that applies different levels of errors into measurements used for parameter estimation. The goal is to study the influence of calibration uncertainty on the temperature detector's readings. The next challenge is a practical realization of the calibration process. A simple experiment is proposed and the least square fit is used to estimate the parameters.

BISHOP, Bradley E., Assistant Professor, "Design of a Cooperative Autonomous Mobile Robot System at the Undergraduate Level," *ASEE Computers in Education Journal*, St. Louis, MO, June 2000, (CD-ROM).

This paper describes an undergraduate-level design project in a course on autonomous mobile robot systems. The project is intended to allow a great deal of latitude in implementation and to promote teamwork and integrated design methodologies in a framework that is both instructional and interesting. The technical challenges of the project include limited bandwidth communications, cooperative multi-agent algorithms, data storage and transmission and physical system design/control. Additionally, the project is structured in such a way as to provide the students experience in organizing large teams of cooperative designers and working with small task-dedicated design teams. This design project was a subcomponent of a course in Autonomous Robot Design in the Systems Engineering Department at the United States Naval Academy.

KIRIAKIDIS, Kiriakos, Associate Professor, and BISHOP, Bradley E., Assistant Professor, "On the Analysis of Uncertain Hybrid Systems with Estimated-State Feedback," *Proceedings of the 2001 American Control Conference*, Arlington, VA, June 2001, (CD-ROM).

In this paper, we present an analysis technique for hybrid linear systems using observers for state feedback control. We present a stability proof for such systems under sector bounded dynamic uncertainties, and discuss the implications of observer feedback for hybrid systems.

Gordon, Diana and KIRIAKIDIS, Kiriakos, Assistant Professor, "Adaptive Supervisory Control of Interconnected Discrete Event Systems," *Proceedings of the 2000 IEEE Conference on Control Applications*, Anchorage, AK, September 2000, pp. 935-940**.**

> Interconnected discrete event systems are able to model large-scale structures, such as in multi-agent applications. These structures, however, are often subject to change. At present, the literature on supervisory control offers only a few remedies for the synthesis of adaptive or robust discrete event systems. This paper proposes a novel approach to adaptive supervision for adaptive systems.

Gordon, Diana and KIRIAKIDIS, Kiriakos, Assistant Professor, "Design of Adaptive Supervisors for Discrete Event Systems via Learning," *Proceedings of the ASME Dynamic Systems and Control Division*, International Mechanical Engineering Congress and Exposition, Orlando, FL, November 2000, pp. 365-370.

> In many practical applications, modeling using event-driven dynamics leads to interconnected discrete event systems. Often, these tend to be large-scale event-varying structures, which need to possess certain event-invariant properties. Although supervisory control theory offers some methods for the synthesis of such discrete event systems, adaptive supervision is, by and large, an open problem. This paper proposes an approach to the design of adaptive supervisors based on a systematic revision of the desirable language, via a learning mechanism, so that the system's properties are safe.

KIRIAKIDIS, Kiriakos, Assistant Professor, "Stabilization of Nonlinear Systems using Quasi-linear Models," *Proceedings of the ASME Dynamic Systems and Control Division*, International Mechanical Engineering Congress and Exposition, Orlando, FL, November 2000, pp. 517-524.

> Unconventional nonlinear models such as nonlinear ARMAX, Takagi-Sugeno fuzzy models, global linearizations, and linear hybrid systems are, at the highest level of abstraction, a sort of quasi-linear models, namely, Polytopic Linear Differential Inclusions (PLDIs). At present, quadratic stability has enabled, mainly via linear matrix inequalities, the analysis and design of a nonlinear system from the vertex matrices of its PLDI model. Proving stability by a globally quadratic Lyapunov function, however, entails conservatism. This paper proposes a less conservative framework by using piecewise-quadratic generalized Lyapunov functions. Further manipulation of the problem within such framework yields a set of bilinear rather than linear matrix inequalities.

LONG, Stephen M., Midshipman 1/C, (USN), PIPER, George E., Associate Professor and BISHOP, Bradley E., Assistant Professor, "The Simulation of Spacecraft Dynamic Motion for the Development of Spacecraft Autonomous Rendezvous and Capture (ARC) Systems," *Proceedings of the Eastern Colleges Science Conference (ECSC)*, Wilkes-Barre, PA, April 2001. **(NOTE: Winner of the Best Paper Award, Engineering Division of the ECSC)**

> The United States Space Program has several high-priority missions on the horizon that will require the capability to perform autonomous rendezvous and captures (ARC) with unmanned space vehicles. Consequently, the development and maturation of the technologies associated with ARC systems is drawing a great deal of interest from researchers and theorists across the nation. Recognizing the high cost that would result from the repeated development, construction, and testing of these systems in a space environment, it is our goal to investigate the possibility of using robotic platforms to accurately simulate spacecraft relative motion in a laboratory. A robust platform for the simulation of spacecraft dynamic motion would greatly reduce the costs associated with the implementation and testing of numerous ARC systems on various space vehicles. This work describes ongoing research to develop a table-top simulation platform using two robotic manipulators, and to use that platform to design and test a simple ARC system.

O'BRIEN Jr., Richard T., Assistant Professor, WATKINS, John M., Assistant Professor, PIPER, George E., Associate Professor and Baumann, David C., " H_∞ Active Noise Control of Fan Noise in an Acoustic Duct," *Proceedings of 2000 American Control Conference*, Chicago, IL, June 2000, (CD-ROM).

In this paper, the problem of reducing fan related noise in an acoustic duct is considered. By installing magnetic bearings on the noise producing machinery, it is possible to co-locate the anti-noise source with the disturbance noise source. This approach allows for global noise reduction through out the duct system. Using H_∞ control theory, an active noise controller is designed that attains broadband as well as tonal noise reduction at all points along the duct. The controller design is based on a state space model identified from an infinite dimensional physical model. Simulation results demonstrate the global nature of this novel active noise control approach.

O'BRIEN Jr., Richard T., Assistant Professor and PIPER, George E., Associate Professor, "Steering Control of an Articulated Vehicle using Differential Braking," *Proceedings of 5th International Symposium on Advanced Vehicle Control*, Ann Arbor, MI, August 2000, (CD-ROM).

The problem of steering the trailer of an articulated vehicle using differential braking was investigated. A nonlinear model of the vehicle was presented and linearized for a vehicle traveling on a curved road at constant speed. A controller was designed using a H_∞ control theory. Numerical simulations were presented to verify the controller's performance.

O'BRIEN Jr., Richard T., Assistant Professor, "Definition of Poles of a Linear, Time-Varying System," *Proceedings of Southeastern Symposium on Systems*, Athens, OH, March 2001, pp. 227-232.

A definition of poles is presented for continuous-time, linear, time-varying systems. For a linear, time-varying state equation, a set of time-varying poles defines a stability-preserving variable change relating the original state equation to an upper triangular state equation. This definition is shown to be a generalization of existing definitions of poles of a linear, time-varying system and is consistent with the definitions for a linear, time-invariant system. A computation procedure is presented using a QR decomposition of the transition matrix for the state equation. A numerical example is given to illustrate this procedure.

PIEPMEIER, Jenelle A., Assistant Professor, "Uncalibrated Vision-Based Mobile Robot Obstacle Avoidance," *Southeastern Symposium on System Theory*, Athens, OH, March 2001, (CD-ROM).

Obstacle avoidance is an important element of mobile robot navigation. Here the obstacle avoidance problem is solved utilizing visual feedback in an optimization-based control technique. This work is part of a larger investigation of uncalibrated vision-based control of unmodelled robotic systems. Specifically, this paper will discuss the control of a mobile robot utilizing a fixed camera. The mobile robot's workspace is within the field of view of the camera. Control is formalized as the minimization of an image-based objective function related to some desired robotic behavior. This function is minimized utilizing a dynamic quasi-Newton method utilizing dynamic recursive least squares Jacobian estimation. An advantage of using Jacobian estimation is that the system model is estimated on-line. This approach provides a generic control method that can be used to control a variety of robotic systems with little *a priori* information. In addition, no camera calibration is necessary, allowing system reconfigurations. For obstacle avoidance, a potential field approach is used to set up repulsive functions around obstacles. The design and implementation of an objective function that will navigate the robot to a goal point while voiding obstacles is discussed.

PIPER, George, Associate Professor, WATERS, Jennifer, Assistant Professor, DWAN, Terrence, Professor, and KIRIAKIDIS, Kiriakos, Assistant Professor, "Teaching Multidisciplinary Engineering Principles Through Environmental Topics," *Proceedings of the 2000 ASEE Annual Conference*, St. Louis, MO, June 2000, (CD-ROM).

For the past three years, the Systems Engineering and the Ocean Engineering Departments at the U.S. Naval Academy have collaborated to offer an innovative course sequence in environmental engineering. In this course

sequence, a host of engineering principles are explored under the umbrella of environmental topics for non-environmental engineering students. This paper presents the techniques used in this course sequence in which engineering principles are either taught or reinforced, and then applied to a real system or problem through environmental topics.

STILWELL, Daniel. J., Assistant Professor and BISHOP, Bradley E., Assistant Professor, "A Strategy for Controlling Autonomous Robot Platoons," *Proceedings of the 2000 IEEE Conference on Decision and Control*, Sydney, Australia, December 2000, pp. 3483 – 3488.

In this paper we address fundamental issues in the control of platoons of cooperating autonomous robotic vehicles. Our primary goal is to reduce explicit communication requirements for cooperative behaviors, allowing sophisticated system-level performance under tight communication bandwidth restrictions, such as those experienced in underwater operations. We present a new operational objective framework based on the regulation of functions of the global platoon state under decentralized control. Simulation results are presented for a simplified autonomous underwater vehicle platoon.

STILWELL, Daniel J., Assistant Professor and BISHOP, Bradley E., Assistant Professor, "A Strategy for Controlling Autonomous Robot Platoons," *Proceedings of the IEEE Conference on Decision and Control*, Sydney, Australia, December 2000, pp. 3483-3488.

Development of decentralized control systems for platoons of robotic vehicles often requires direct communication between vehicles. Using basic tools from the field of decentralized control, we develop a framework from which existence of vehicle controllers can be assessed for a given communication structure. This approach to control design allows us to investigate minimum inter-vehicle communication solutions. Simulation results are presented for a platoon of autonomous underwater vehicles.

WATKINS, John M., Associate Professor, Brown, Gary and Blumenstock, Ken, "Control of Integrated Radial and Axial Magnetic Bearings," *Proceedings of the 33rd Southeastern Symposium on System Theory*, Athens, OH, March 2001.

The goal of this research is to develop a magnetically suspended momentum wheel capable of actively reducing imbalance vibrations. Typically, this would require two radial magnetic bearings with separately energized x and y-axes and one axial bearing. In this system, however, the radial and axial functions were combined into a single design for a more compact and elegant package. One downside of the integrated bearings is increased coupling between the radial and axial degrees of freedom. Closed-form solutions are developed for the bias and control forces acting independently. Implications on feedback control design are discussed.

WATKINS, John M., Associate Professor, and MITCHELL, E. Eugene, Professor, "A MATLAB Graphical User Interface for Linear Quadratic Control Design," *Proceedings of the Frontiers in Education Conference*, Kansas City, Kansas, October 2000.

The optimal Linear Quadratic Regulator (LQR) method is a powerful technique for designing controllers for complex systems that have stringent performance requirements. For most realistic applications, the LQR problem must be solved via a Computer-Aided-Design (CAD) package such as MATLAB. With the CAD packages solving the optimization problems, the challenge lies in how the weighting matrices are chosen. With experience, practicing engineers become quite adept at choosing these matrices for a specific application. Students in a typical quarter or semester long course do not have the luxury of this experience. Consequently, the authors of this paper have written a MATLAB Graphical User Interface (GUI) that allows the students to easily "tune" the weighting matrices and immediately see the consequences of those changes. This paper describes the motivation behind the LQR Design GUI, the GUI construction process, and the use of the LQR Design GUI in the senior-level modern control systems course at the U.S. Naval Academy.

WICK, Carl E., Associate Professor and KNOWLES, Kenneth A., Professor, "USS Tanglewire: An Experiment in Networking for and Embedded Computer Application Class," *Proceedings of the American Society of Engineering Education Convention*, St. Louis, MO, 2000. **(Note: Winner of the "Best Paper" award from the Computers in Education Division of ASEE)** (CD-ROM).

Small embedded microprocessors are used routinely as controllers in many types of consumer, industrial and military electronic devices. In many cases more than one of these small computers are used in a product to affect distributed control, or to localize specific system functions. This tends to modularize the system and helps to make it more reliable, survivable, configurable and upgradeable. Networks provide the "glue" that connects each of the localized modules together into a functioning whole. We believe that students who take courses in microprocessor embedded control should have some exposure to network-connected control systems, and if possible they should also have experience in their implementation. This paper describes a project that we undertook at the U.S. Naval Academy in our computer engineering track where our students used an I^2C network and PIC16C84 microprocessors to construct a model distributed shipboard damage control system.

ZIVI, Edwin, L., Assistant Professor, CERRITO, Jonathan J., Midshipman 1/C, (USN), and DONEY, George D., Lieutenant, USN, "Neural Network Fault Tolerant Estimation of an Integrated Power System," *Proceedings of Applied Simulation and Modeling Conference*, Banff, Canada, July 2000, (CD-ROM).

A feed forward back-propagation neural network is investigated for fault tolerant estimation of a nonlinear, variable structure Integrated Power System. Neural networks can be robust in the sense that they are not disabled by incomplete or inconsistent information. The ability of a neural network to adapt to unforeseen eventualities such as flooding, fire, and combat casualties is presented for a complex, interactive power system. In particular, the performance of the neural network with respect to sensor degradation and changes in the system configuration is reported. In essence, we train the neural network to distinguish between changes in the physical system and degradations in the sensor suite. The Integrated Power System under consideration will provide propulsion and ship's service power generation and distribution for the DD-21 next generation strike destroyer.

ZIVI, Edwin L., Assistant Professor and PIEPMEIER, Jenelle A., Assistant Professor, "Dynamic System Animation Within a Simulink Laboratory Environment," *Proceedings of the ASEE 2001 Annual Conference*, American Society for Engineering Education, Albuquerque, NM, June 2001, (CD-ROM).

Recent innovations in the animation of student developed, laboratory simulations have been found to significantly improve student understanding and enthusiasm. This animation can be implemented using MATLAB s-functions that are typically called from a Simulink simulation. These rudimentary animations have been found to be relatively easy to construct and well received by students. General observations and recommendations are developed from specific examples, hints, and experiences. Runtime animation has been found to be a valuable complement to the existing capability to visually construct the simulation model. S-function animations have been found to be composed of two primary elements: reusable interface/initialization "boilerplate" and animation specific graphics. To date, animations have been developed solely as part of faculty course preparation. These animations have been found to efficiently leverage MATLAB's high level programming features to provide an effective teaching tool.

Technical Reports, Book Reviews and Book Chapters

STILWELL, Daniel J., Assistant Professor and BISHOP, Bradley E., Assistant Professor, "Communication, Feedback, and Decentralized Control for Platoons of Underwater Vehicles," U.S. Naval Academy Division of Engineering and Weapons, EW-05-00, August 2000.

Many researchers have proposed that multiple, cooperating robots or autonomous vehicles present significant benefits over single-unit approaches in a variety of domains. In this technical report, we present control-theoretic approaches to characterization of required communications for platoons of cooperating vehicles, and discuss the

nature of the decentralized control problem for Autonomous Underwater Vehicles. Extensive proofs and details regarding the controller development are included in this technical report that are not discussed in the published record.

STILWELL, Daniel J., Assistant Professor and WICK, Carl E., Associate Professor, "Current Status and Near-Term Goals of Miniature/Modular Autonomous Underwater Vehicle Research at the United States Naval Academy," Northrop Grumman Oceanic Systems, December 2000.

The Naval Academy, through the Unmanned Underwater Vehicles Laboratory (UUV Lab), is actively pursuing research in the theory and technology of miniature/modular autonomous underwater vehicles (AUVs) and in platoons of AUVs. In this report, we present several open research topics that we believe are enabling technologies for employing mini/modular AUVs. In addition, we discuss current and planned UUV Lab-sponsored projects that address these open research topics.

STILWELL, Daniel J., Assistant Professor and WICK, Carl E., Associate Professor, "Development of a Miniature Autonomous Underwater Vehicle and Evaluation of Guidance Systems," Northrop Grumman Oceanic Systems, December 2000.

A miniature autonomous underwater vehicle (Mini-AUV1) was constructed to explore the feasibility of, and to determine technical issues that are associated with low-cost autonomous vehicles for a variety of shallow underwater military and non-military missions.

STILWELL, Daniel J., Assistant Professor and BISHOP, Bradley E., Assistant Professor, "Platoons of Underwater Vehicles: Communication Feedback, and Decentralized Control," *IEEE Control Systems Magazine*, Vol. 20, No. 6, pp. 45-52, 2001. (invited contribution)

Communication requirements, especially with regard to bandwidth limits, are often challenging obstacles to control system design. In this work, we are interested in the development of a design methodology and analysis technique for controlling platoons of autonomous vehicles with a focus on understanding communication requirements for such systems. We present a decentralized control framework applicable to platoons of mobile robots or vehicles and, for illustration, consider a simplified design example for a platoon of autonomous underwater vehicles (AUVs). An underwater example is chosen to highlight the need for control strategies that address reduced communications since communication bandwidth is severely limited underwater.

Presentations

AVRAMOV-ZAMUROVIC, Svetlana, Associate Professor and WICK, Carl E., Associate Professor, "Microcontroller Web Connectivity," Pervasive Computing 2001 Conference, Gaithersburg, MD, May 2001.

BISHOP, Bradley E., Assistant Professor, "Design of a Cooperative Autonomous Mobile Robot System at the Undergraduate Level," 2000 ASEE Annual Conference, June 2000.

BISHOP, Bradley E., Assistant Professor, "Control Techniques for Platoons of Autonomous Vehicles," Control and Decision Seminar Series, Institute for Systems Research, University of Maryland, College Park, MD, 6 April 2001. (invited lecture)

DeMOYER, Robert, Professor, "Interactive Continuous and Discrete Step Response Using MATLAB GUI's," 2000 ASEE Annual Conference, St. Louis, MO, June 2000.

DWAN, Terrence E., Professor, "Teaching Multidisciplinary Engineering Principles Through Environmental Topics," 2000 ASEE Annual Conference Proceedings, St. Louis, MO, June 2000.

HENRIQUEZ, Luis R., Midshipman 1/C, USN and KIRIAKIDIS, Kiriakos, Assistant Professor, "Supervision of a Platoon of Robots," National Conference on Undergraduate Research, Lexington, KY, March 2001.

KIRIAKIDIS, Kiriakos, Assistant Professor, "Adaptive Supervisory Control of Interconnected Discrete Event Systems," IEEE Conference on Control Applications, Anchorage, AK, September 2000.

KIRIAKIDIS, Kiriakos, Assistant Professor, "Stabilization of Nonlinear Systems using Quasi-linear Models," Proceedings of the ASME Dynamic Systems and Control Division, International Mechanical Engineering Congress and Exposition, Orlando, FL, November 2000.

KIRIAKIDIS, Kiriakos, Assistant Professor, "Design of Adaptive Supervisors for Discrete Event Systems via Learning," Proceedings of the ASME Dynamic Systems and Control Division, International Mechanical Engineering Congress and Exposition, Orlando, FL, November 2000.

KNOWLES, Kenneth A., Professor, "The Hubble Space Telescope: The Human Connection," Combined Meeting of the American Institute of Aeronautics and Astronautics Space Systems Technical Committee, Baltimore Section, National Capitol Section, and USNA Student Chapter, U.S. Naval Academy, Annapolis, MD, March 2001.

LONG, Stephen M., Midshipman 1/C, (USN), PIPER, George E., Associate Professor and BISHOP, Bradley E., Assistant Professor, "The Simulation of Spacecraft Dynamic Motion for the Development of Spacecraft Autonomous Rendezvous and Capture (ARC) Systems," Eastern Colleges Science Conference, Wilkes-Barre, PA, April 2001. **(NOTE: Winner of the Best Presentation Award, Engineering Division of the ECSC)**

O'BRIEN Jr., Richard T., Assistant Professor, " H_∞ Active Noise Control of Fan Noise in an Acoustic Duct," 2000 American Control Conference, Chicago, IL, June 2000.

O'BRIEN Jr., Richard T., Assistant Professor, "Steering Control of an Articulated Vehicle using Differential Braking," 5th International Symposium on Advanced Vehicle Control, Ann Arbor, MI, August 2000.

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STILWELL, Daniel J., Assistant Professor, "Decentralized Control for Platoons of Autonomous Underwater Vehicles," Johns Hopkins University, Mechanical Engineering Department, Baltimore, MD, February 2001.

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