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CONTROLS AND GUIDANCE RESEARCH

ANNUAL REPORT

Prepared for

NASA CENTER OF RESEARCH EXCELLENCE
SCHOOL OF ENGINEERING
NORTH CAROLINA A&T STATE UNIVERSITY

by

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A. AREA SUMMARY

The objectives of the control group are concentrated on research and education. The control problem of the Hypersonic Space Vehicle represents an important and challenging issue in aerospace engineering. The work described in this report is part of our effort in developing advanced control strategies for such a system. In order to achieve the objectives stated in the NASA-CORE proposal, the tasks were divided among the group based upon their educational expertise. Within the educational component we are offering a Linear Systems and Control course for students in Electrical and Mechanical engineering. Also, we are proposing a new course in Digital Control Systems with a corresponding laboratory.

Organization

In this research, attention is focused on the development of control strategies for the hypersonic vehicles based on adaptive control, robust control and (improved) inverse dynamics control (see Figure 1), and variable structure control. New control schemes are under-way for the vehicle under consideration.

This area annual report is organized as follows.

Research Task 1 - Development of optimal trajectory
Research Task 2 - (NASA Langley): Investigation on Mathematic modeling and Advanced Control of Hypersonic Vehicle
Research Task 3 - Design of Fuzzy Controllers for Autonomous docking and rendezvous
Research Task 4 - Calculate Flight Dynamics of hypersonic vehicle
Research Task 5 - Vibration Modeling/ Smart structure
Educational Component
Budget
Publications

Area Focus

The goal of the control and guidance group is to develop control strategies based on conventional and adaptive control methodologies. The control strategies are based on linear and nonlinear system dynamics. In considering hypersonic vehicle performance, subjects such as: model uncertainties, trajectory, vibration, manuverablity, fuel consumption, computer expert guidance, and others performance may be improved by using control.

Immediate and Long Range Objectives

1. Development of adaptive control strategies for the hypersonic vehicle
2. Development of robust control strategies for the hypersonic vehicle

3. Development of control laws for take, normal flight and landing flight for the hypersonic vehicle
4. Study the feasibility of fuzzy controller for hypersonic vehicle
5. Computer simulation of controlling hypersonic vehicle dynamics and vibration
6. Optimal Trajectories for hypersonic vehicle control simulation
7. Development of control Laboratory
8. Development of MEEN 652 Aero Vehicle Stability and Control
9. Experimental verification of control models
10. Experimental verification of vibration and dynamic models
11. Experimental verification of computer simulation of selected hypersonic vehicle subassemblies in combination with the control system.
12. Development of adaptive guidance for hypersonic vehicle

B. AREA RESEARCH PROJECTS

The specific tasks of the members for the control and guidance group along with publications are listed. Also, the tasks done by the undergraduate students and the travel made by the faculties/students to the international conferences and different NASA centers are presented. We are pleased to announce that Mr. Ed McCormick defended his MSEE through the corporate fund (Honeywell/Alliant Tech) and NASA-CORE in August of 1992.

Research Task 1 (NASA Langley): (Dr. Song)

One of the objectives of the control group is the development of optimal trajectories and guidance for a hypersonic vehicle. The work described in this section is part of our effort in developing advanced control strategies for such system. The fuel-optimal ascent of a single-stage-to-orbit vehicle using air breathing propulsion is the focus of research in advance control and guidance. Due to the high degree of complexity of the problem, we are attempting to investigate the applicability of the many state-of-the-art optimization techniques. Specifically, we will study the validity of the control laws based on the direct, indirect, inverse dynamic, and numerically motivated methods based on evolution strategy during take-off and landing. Difficulty arises in the solution of the two-point-boundary-value problem (TPBVP) resulting from the application of the necessary conditions. During the initial phase, the vehicle is a bench mark wing-cone configuration reported in the literature. As the research progresses, we will also concentrate on development of advanced control strategies and contact verifications.

Next, we consider the application of the methods presented earlier to the design of adaptive controllers. Our interest in adaptive control arises from possible parameter uncertainty in the rigid body dynamic equations of motion. Throughout the life of the spacecraft, its dominant rigid body dynamics may change due to loss of mass or changes in mass distribution, configuration, etc. These changes have the effect of modifying the system inertia. The motivation for the design of the adaptive controller is to provide compensation for structural model uncertainty.

Research Task 2 (NASA Langley) - Dr. Song
Mathematic Modeling and Advanced Control of Hypersonic Vehicle

The control problem of the Hypersonic Space Vehicle represents an important and challenging issue in aerospace engineering. The work described in this report is part of our effort in developing advanced control strategies for such a system.

As we understand, hypersonic vehicle is a highly nonlinear and strongly coupled system. Its dynamic behavior is fast time varying. Furthermore, due to the fact that there always exist uncertain system parameters and external disturbances as well as structural flexibility, the overall system dynamics is uncertain. As a result, precise model of such system is not available, which calls for the control strategies that are not based on the exact system model.

In this research, attention is focused on the development of adaptive control, robust control and (improved) inverse dynamics control (see Figure 1). Motivated by our earlier work on nonlinear robotics systems [6-8], new control schemes for aircraft systems are proposed which achieve stable trajectory tracking and vibration suppression. It is shown that these strategies guarantee satisfactory operational performance in the face of modeling uncertainties and external disturbances.

This report is organized as follows. The work on nonlinear robotics systems, which is the direct motivation of the control strategies for aircraft systems, is presented first. This include paper 1, paper 2 and pacer 3. Secondly, we report the new robust control scheme for a class of nonlinear dynamic systems with application to hypersonic vehicle modeled by lumped mass approach. In this work, instead of assuming that the mass matrix M and the stiffness matrix K are exactly known, we consider the case where uncertain parts are involved in these matrices. Such consideration is of importance in practice. Finally, a new approach to controller design for aerodynamic systems is presented. Fundamentally, this is the so-called inverse dynamics. However, the essential difference is that our approach is an improved version, because an extra compensation is introduced, which make the over system either adaptive, or robust.

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Research Task 3 (Marshall Space Center) - Dr. Homaifar

This work examines the implementation of a fuzzy logic six degree-of-freedom controller for a general purpose spacecraft. This controller will provide autonomous docking capabilities for the spacecraft based on radar or other ranging data.

The six degree-of-freedom controller actually consists of six one degree-of-freedom controllers, one each for roll, pitch, yaw, range, elevation, and azimuth. Development of the controller began with the inclusion of code to determine translation information from the radar subroutine. Rotation information (roll, pitch, and yaw) was already provided for use in the proportional derivative autopilot controller which the fuzzy controller replaces. Work was then done fuzzifying the appropriate input angles, distances, and rates for use by the controller. Fuzzification encompasses the partitioning of the input spaces into membership functions which consist of separate but overlapping fuzzy sets. After fuzzification, the input data is passed through the rule set and the output is determined by matching the appropriate rules with the data. The output of the controller are three separate forces for range, azimuth, and elevation and three torques for roll, pitch, and yaw. The specific goals here can be stated as:

1. Improvement of control system and guidance
2. Reduction of overall computational burden

Research Task 4 (NASA-Langley) - Dr. Lai
Calculate flight dynamics of hypersonic vehicle

The combination of collocation with non-linear programming has resulted in a method of rapidly generating optimal trajectories. This method has been embodied in the Optimal Trajectories by Implicit Simulation (OTIS) program. The solution of optimal control problems by direct transcription using collocation and non-linear programming will be used to support hypersonic aerospace vehicle design studies. Applications of solutions to hypersonic cruise, constrained fly-outs, and optimal approach to landing will be studied. The flight dynamics optimization is a multi-disciplinary research area for conceptual and preliminary design and evaluation of advanced aircraft concepts. It consists of primary research subjects:
1) weights, 2) aerodynamics, 3) engine cycle analysis, 4) mission performance, 5) takeoff an landing.

The weights estimation will use statistical/empirical equations to predict the weight of each item in a group weight statement. We will incorporate a analytical wing weight estimation capability available for use with more complex wing platforms. Centers of gravity and moments of inertia will be calculated for multiple fuel conditions. The aerodynamics estimation will use the EDET (Empirical Drag Estimation Technique) to provide drag polars for performance calculations. Modifications include smoothing of the drag polars, more accurate Reynolds number calculations, and the inclusion of the Sommer and Short T method for skin friction calculations. Alternatively, drag polars may be input and then scaled with variations in wing area and engine (nacelle) size. The engine cycle analysis will be based on the QNEP. It provides the capability to internally generate an engine deck consisting of thrust and fuel flow rate at a variety of Mach-altitude conditions. Engine cycle definition decks will be provided for turbojets turboprops, mixed flow turbofans, separate flow turbofans, and turbine bypass engines. The mission performance estimation will use the calculated weight, aerodynamics, and propulsion system data to calculate performance.

Based on energy considerations, optimum climb profiles will be flown to start of cruise conditions. The cruise segments may be flown at the optimum altitude and/or Mach number for maximum range or endurance, at the long range cruise Mach number, or at a constant lift coefficient. Descent may be flown at the optimum lift-drag ratio. In addition, acceleration, turn, refueling, payload release, and hold segments may be specified in any reasonable order. Reserve calculations can include flight to an alternate airport and a specified hold segment. The takeoff and landing analysis included the computation of the all-engine takeoff field length, the balanced field length including one-engine-out takeoff and aborted takeoff, and the landing field length. The approach speed will also be calculated, and the second segment climb gradient and the missed approach climb gradient criteria will be evaluated. The system will have the capability to generate a detailed take off and climb out profile for use in calculating noise footprints.

The study will include the analysis of a point design, parametrically varying certain design variables, (for minimum gross weight, minimum fuel burned, maximum range) using nonlinear programming techniques. The Fiacco-McCormick penalty function may be used with the Davidson-Fletcher-Powell (DFP) or the Broyden-Fletcher-Goldfarb-Shano (BFGS) algorithm. The configuration design variables are wing area, wing sweep, wing aspect ratio, wing taper ratio, wing thickness-chord ratio, gross weight, and thrust (size of engine). The performance design variables are cruise Mach number and maximum cruise altitude. The engine cycle design variables are the design point turbine entry temperature, the maximum turbine entry temperature, the fan pressure ratio, the overall pressure ratio, and the bypass ratio for turbofan and turbine bypass engines.

Research task 5 (NASA-Langley) - Dr. Dunn
Vibration and Smart Structures

A literature search was performed for reported investigations on prior National Aerospace Developments (NASP) and the experimental version of the X-30. The objective of this search was to obtain a list of various topics related to NASP research so that future work would parallel and have possible applications to NASP development. Pertinent information related specifically to integral systems engineering and programmatic development was sought so as to pick topics that could be integrated into A&T's CORE disciplines of computational fluids, controls, structures, and human factors/tele-operations. Also, a topic was sought that would broaden my own area of expertise while also providing an additional area of expertise at A&T.

Smart (active and instrumented) structures and materials is another component investigated within the control and guidance group. The focal points of this study are: 1) structure flexibility and vibration issues due to the constraint of reduced weight, 2) controlling the contour of aerodynamic surfaces due to loading and temperature, and 3) controlling the contour of surfaces inside a Hyper-sonic jet engine to enhance propulsion. These materials could provide utility as integral sensors throughout NASP to monitor vehicular performance and to announce trouble.

Significant smart materials work is underway, as reported in the literature, in the area of composite materials which are combinations of traditional composites and piezoelectric materials where the piezoelectric material provides the active actuation and passive sensing element. An alternative area of prime interest is the development of composite structures and laminates with internal pressurization to provide the active actuation component to control the structures load and deformation response. By venturing away from composites with lay-ups which try to approach characteristics of isotropic materials, structures might be developed that would respond to loads advantageously and allow internal pressure to control the displacement of the structure and adverse stresses as needed. The working fluid used for internal pressurization may possibly be used to combine systems. One possibility is that this fluid space could be used for fuel storage. Another is that this fluid could also be utilized in cooling. Such combinations of functions for the working fluid could have possible advantages.

C. AREA PROGRAM ACTIVITIES

The control and structure group began its activities in the Center on January 4, 1992. Drs. Homaifar and Lai had released time for both fall and spring semester, while Dr. Dunn had released time during fall 1992. Also, Dr. Homaifar put two and half months during summer of 1992. Dr. Song joined the group as of August 10, 1992, where he is doing research full time.

Educational Component

The control group offered Linear Systems and Control(ELEN 410) during the Fall 1992. This course will be offered again on the spring of 1993. The course is open for seniors in Mechanical, Industrial and Electrical Engineering. The course includes: control system modeling and representation, features of feedback control system, state space representation, time domain analysis, root locus, and design compensation. This course is being offered to students in Electrical and Mechanical Engineering. The course syllabus and requirement is given in Appendix A. Also, ELEN 668 (Advanced Automatic Control course is listed as an option for the students specialized in Aerospace discipline as an option in Mechanical engineering. Also, a new course MEEN 652 Aero Vehicle Stability and Control will be developed as an option for the students specialized in Aerospace discipline as an option in Mechanical engineering.

Computer System and Software Purchases

In order to familiarize the student in ELEN 410, with different compensators and to provide a thorough understanding of the different characteristics of the compensators, the following computer packages are acquired:

Personal Computers: 3 (486 DX/50Mhz)
Visual Solutions' software package for PC (2 units)
MATHLAB for workstation: Control System Toolbox
Robust-Control Toolbox

The designs of the compensators are interactive, thus the students can visualize the changes made in the coefficients of the compensators.

Laboratory Development (Target date August 93)

The analog control systems laboratory will have (as a goal) to teach the student the practical aspects of continuous-time dynamical system modeling, analysis, design and simulation, and will consist of the following experiments:

- Scaling instrumentation variables and programming differential equations on analog computers.
- Determination of transfer function of dynamical systems using frequency response methods.
- Transient response of dynamical systems via analog computer simulation.
- Stability analysis of dynamical systems modeled by differential equations.
- Open-loop and closed-loop velocity control using analog computer models.
- Position control using conventional cascade compensators (lag, lead, and lag-lead).
- Minor feedback loop compensation techniques.
- Implementation of elementary state variable observers.
- Laboratory design project; e.g., analog computer simulation of a compensated physical system which takes into account nonlinear effects such as back lash, saturation, dead zones, etc.

Travel

1. HBCU Orientation Conference (Steven Lai, A. Homaifar)
2. Marshal Space Flight Center (Steven Lai, A. Homaifar)
3. Attend workshop on Distributed Parameters (Steven Lai, A. Homaifar)
4. Attend and Present Paper at International Symposium (SPIE) in Mathematical

Engineering (Homaifar, McCormick)

5. Attend and Present Paper at Second International Conference on Automation Technology (Steven Lai)
6. Attended workshop on Thermal Protection Systems (TPS) at NASA-Langley (DeRome Dunn)
7. Travel to NASA-Lewis for ten weeks as NASA-ASEE summer faculty fellow located within the structures division in the fatigue and fracture branch (DeRome Dunn)

Date: May 9-11, 1992
From: Greensboro, NC
Destination(s): Marshal Space Center, Huntsville, AL
Purpose: To visit facilities at site
Cost: $ 472.00

Date: March 24-27, 1992
Destination(s): Washington, DC and Hampton, VA
Purpose: To participate in HBCU-NASA conference
Cost: $ 414.09

Date: June 9-11, 1992
Destination(s): Williamsburg, VA
Purpose: To attend workshop
Cost: $ 364.50

Date: May 28-29, 1992
Destination(s): Hampton, VA and Washington, DC
Purpose: To discuss project with technical monitor
Cost: $ 340.77

Date: December 14-20, 1992
Destination(s): Tuscon, AZ
Purpose: 31st IEEE Conference on Decision and Control, and attend a workshop
Cost: (Estimated) $1624.80

Date: November 17-19, 1992 (Professor Wei-Bing Gao)
From: Beijing, China
Destination(s): Greensboro, NC
Purpose: To give seminar in control and guidance of hypersonic vehicles
Cost: $1010.00

D. FACULTY AND STUDENT PARTICIPATION

Faculty Participants

Name:	Abbie Homaifar (Electrical Engineering)
Classification:	Coordinator
Citizenship:	Iran
Research Activity:	Work on application of Adaptive control, Fuzzy controller strategies related to hypersonic plane
Telephone:	(919)-334-7760 Room 537, McNair Hall North Carolina A & T State University Greensboro, NC 27411

Name:	DeRome Dunn (Mechanical Engineering)
Classification:	Group member
Citizenship:	US
Research Activity:	Development of computational methods for Vibration of smart material
Telephone:	(919)-334-7620 Room 636, McNair Hall North Carolina A & T State University Greensboro, NC 27411

Name:	Steven Lai (Mechanical Engineering)
Classification:	Group member
Citizenship:	US
Research Activity:	Flight dynamics of hypersonic vehicle, and smart materials
Telephone:	(919)-334-7620 Room 623, McNair Hall North Carolina A & T State University Greensboro, NC 27411

Name:	Yong-Duan Song (Electrical Engineering)
Classification:	Research Associate
Citizenship:	China
Research Activity:	Work on adaptive control, nonlinear control theory, robust control and their applications to hypersonic vehicle
Telephone:	(919)-334-7255 Center Office, Woodson Building North Carolina A & T State University Greensboro, NC 27411

Student Participants

SUMMER, 1992

Undergraduate students:

Name: Christen Bonita Williams (Junior, Electrical Engineering)
Citizenship: US
GPA: 3.21
Research Advisor: Dr. Homaifar, and Dunn

Name: Lamark Chance(Junior)
Citizenship: US
GPA: 3.08
Research Advisor: Drs. Homaifar, and Lai

Name: Robert Lynn Dismuke (Senior, Electrical Engineering)
Citizenship: US
GPA: 3.60
Research Advisor: Dr. Homaifar

FALL, 1992

Name: Christen Bonita Williams (Junior, Electrical Engineering)
Citizenship: US
GPA: 3.21
Research Advisor: Dr. Homaifar, and Dunn

Name: Lamark Chance(Junior)
Citizenship: US
GPA: 3.08
Research Advisor: Drs. Lai, Song

Name: Nikki Smith (Senior, Electrical Engineering)
Citizenship: US
GPA: 3.60
Research Advisor: Dr. Homaifar

Graduate students

FALL, 1992

Name: Kevin Barnhart (Electrical Engineering)
Citizenship: US
Classification: First semester
Research Advisor: Dr. Lai

Name: John Hogans (Electrical Engineering)
Citizenship: US
Classification: Third semester-GEM Fellow
Research Advisor: Dr. Homaifar

Name: Nadeem Bowe (Electrical Engineering
Citizenship: US
Classification: Third semester-GEM Fellow
Research Advisor: Dr. Homaifar

Summary of Student Involvement

Each student was assigned several separate jobs that contributed to the overall research activities. The tasks which were split among the students included:

1. Research on the dynamics and background of control systems and several documents from the Marshall Space Program.
2. Analysis of the FORTRAN computer program which accompanied the aforementioned documents.
3. Assistance for graduate students in their theses. One involves the design of fuzzy controllers using genetic algorithms (GAs), and the other involves non-linear constrained optimization by GAs and its comparison with other existing methods of solution. Within this task, the undergraduate students were exposed to the use of the C programming language.
4. Introduction to VisSim software, a package that involves creating block diagrams and simulation with the use of advanced engineering graphics
5. Exposure to writing and preparing papers for publication.

John E Hogans IV

1. Development of real time adaptive fuzzy controllers. The research will include a study of large population GA and Evolution strategies. ES will be used for the adaptive control law development. Currently, he is reading background materials on fuzzy controllers.
2. MRI Brain Scan images using Genetic Algorithms for Bowman Gray School of Medicine. The amount of grey matter, white matter, and cerebral spinal fluid (CSF) contained in the image was to be quantified automatically using a histogram of the MRI image.

Kevin Barnhart

Mr. Barnhart is working on the development of flight dynamic models. He is currently involved in a literature survey of articles related to the guidance and control of aircraft. In addition, he is studying the basic principles involved with rigid body dynamics and aerodynamics.

Nadeem Bowe

Mr. Bowe is working on the subject entitled "System Identification Via Evolution Strategy Employing Group Method Data Handling Techniques." The central problem in system control and prediction is the formation of a suitable mathematical model given some small amount of noisy system measurements. In addition, an unknown system may be potentially nonlinear and thereby difficult to describe by deterministic methods. It is with this in mind that the attempt to employ the Group Method Data Handling (GMDH) approach with Evolution Strategy (ES) is motivated. Two such systems to be explored are, the Glass-Mackey Equation:

$$\frac{dx}{dt} = \frac{ax(t-\tau)}{1+x^{10}(t-\tau)} - bx(t) \quad (1)$$

and the Logistic Equation:

$$x(t+1) = \lambda x(t)(1-x(t))$$

Both of these functions generate chaotic data and would be difficult to characterize given a small number of data points.

Taking cues from Kargupta and Smith's paper,"System Identification with Evolving Polynomial Networks," the author will attempt to demonstrate that the GMDH/ES combination is a more robust method than either GMDH or Genetic Algorithms alone in deriving a suitable model for system prediction and identification.

E. PROGRAM IMPACT AND FINANCIAL REPORT

Drs. Homaifar, Lai and Dunn were the supervisors to all of the students who participated in the research. They provided the background and documents to begin working on the required tasks assigned by NASA and made all the necessary arrangements for the students to work in the laboratory both on and off the computer. Dr. Homaifar instructed the students, advised them, and gave the appropriate tasks to them. This program provide the students good understanding of control theory and technology in application to aerospace engineering research. Many publications resulting from this research program are listed below.

Publications

1. A. Homaifar, and E. McCormick, " Full Design of Fuzzy Controllers Using Genetic Algorithms", Proceedings of the Neural and Stochastic Methods in Image and Signal Processing at the International Society of Optical Applied Science and Engineering. July 18-24, 1992.
2. A. Homaifar, E. McCormick, " A New Approach for the Design and Implementation

of Fuzzy Controllers", The IEEE Proceedings of the Southeastern Symposium on System Theory, and Third Annual symposium on CSA, Greensboro, NC 1992.

3. **H.Y. Lai and A. Homaifar, 1992, "Design of Fuzzy Controllers Using Genetic Algorithms," The Second International Conference on Automation Technology, July 4-6, 1992.**
4. **A. Homaifar, H.Y. Lai, and Ed McCormick, 1992, "Design Optimization of Turbofan Engines Using Genetic Algorithms," (Submitted).**
5. **A. Homaifar, H.Y. Lai, and X. Qi, " Constrained Optimization Via Genetic Algorithms", (Submitted).**
6. **Y. D. Song, J. N. Anderson, A. Homaifar and H. Y. Lai, Robust Motion Tracking Control of Robotics Arms Based on the Generalized Energy Accumulation Principle, to appear in IEEE *Int. Conf. on Decision and Control*, December 1992, Tucson, Arizona.**
7. **Y. D. Song, J. N. Anderson, A. Homaifar and H. Y. Lai, System Stability and Performance Analysis Based on Generalized Energy Accumulation: Part II - Applications, to appear in IEEE *Int. Conf. on Decision and Control*, December 1992, Tucson, Arizona.**
8. **Y. D. Song, J. N. Anderson, A. Homaifar and H. Y. Lai, Nonlinear Robust Controller Design for Multi-Robotics Systems with Unknown Payloads, *The Fourth NASA Conf. on Muli-Robot Systems*, New York, November, 1992.**

Area Financial Report

1. **Faculty**

	Spring(@25%)	Fall(@25%)	Summer(2.5 months
Abbie Homaifar	$5,142.00	$5,194.00	$11,427.00
DeRome Dunn	$4,654.00	-	-
Steven Lai	$5,656.00	$5,713.00	-
Y.D. Song		$2,760.00	$12,420.00(@100%)

Total Release Time =	$ 52,967.00
2. Research Assistant (Two Graduate)	$ 8,100.00
3. Fringe Benefit (24% of 1)	$12,712.00
4. Social Security (7.65% of 2)	$ 620.00
5. Indirect Cost (55% of 1)	$29,131.00
6. Other Direct Cost	
Undergraduate Stipend	$ 7,442.00
Tuition	$ 1,310.00
Lab Setup	$15,984.00
Printing	$ 500.00
Office Supply	$ 272.00
Travel	$ 4,699.00
TOTAL	$133,737.00

Equipment Purchased

Vendor 1:	**Digitz**
Items:	**Texas Instruments Microlaser Turbo (Part #2559821-4501)**
	Texas Instruments Toner (Part #2550770-0001)
	1 MB RAM Third Party Equivalent to Part#2555739-0001
Cost:	**$1,982.06**

Vendor 2:	**MGA**
Items:	**ACSL/PC 3.5 inch diskettes**
Cost:	**$1010.00**

Vendor 3:	**United Office & Business Concept**
Items:	**3 Deluxe Desk Dispensers**
	1 dozen Uniball Pens
	3 Scotch Brand Magic Tape Dispensers
	1 box white Envelopes
	3 boxes Kraft Envelopes
	2 boxes brown Kraft Clasps
	2 boxes brown Kraft Envelopes
Cost:	**$ 271.66**

Vendor 4:	**North Carolina A & T State University**
Items:	**3 Copier Cards for Literature Research**
Cost:	**$500.00**

Vendor 5:	**Tri-Star Computer Corporation**
Items:	**3 TRI*CAD YZ-250 VESA Local Bus Systems**
Cost:	**$12,992.30**