INVESTIGATION OF AIR TRANSPORTATION TECHNOLOGY AT OHIO UNIVERSITY 1989-1990

Robert W. Lilley
Department of Electrical and Computer Engineering
Ohio University
Athens, Ohio

SUMMARY OF RESEARCH

The Joint University Program (JUP) offers to students, faculty and professional staff the opportunity to contribute to the utility and safety of air transportation. At Ohio University, the program is structured to offer these opportunities to both graduate and undergraduate students. The program demands high-quality technical work, quarterly presentation and defense of the work, and publication at conferences and in journals. Under the general direction of the Principal Investigator, Joint University Program operations are led day-to-day by a selected Ph.D. candidate, who gains both technical and project leadership skills. During 1989-90, Frank van Graas, having achieved his Ph.D., has been gradually turning over the program to Michael Braasch. The annotated bibliography given below documents the technical activities and outputs for the year. Perhaps more important are the continuing careers of 1989-90 Joint University Program graduates:

James D. Waid - Graduated with the BSEE. He is currently with NASA Ames Research Center and will begin a Master's program at Stanford University in September 1990.

David S. McIntyre - Received the MSEE and is now with The Analytic Sciences Corporation (TASC), working with aircraft antenna systems.

Craig B. Parker - Completed the MSEE and is now with the Bendix-King Radio Company, a major avionics manufacturer.

Mark R. Kuhl - Received the MSEE and is now with Ashtech Inc., a GPS receiver manufacturer.

Paul A. Kline - Graduated with the BSEE with high honors, and remains with the Joint University Program as a graduate intern.

These JUP alumni carry both education and training to their new positions; they leave to the JUP their accomplishments while in school. The new students joining the program build on this plateau.

The JUP students have been regular (and very successful) entrants in the RTCA Jackson Award competition. Frank van Graas' receipt of the award for 1989 recognizes both his work and the program which made it possible. Messrs. Michael Braasch and David McIntyre won honors at the 2nd International ION Satellite Division meeting. Once again, this demonstrates the value of the JUP in preparing young engineers and scientists for effective careers.

During 1989-90, five topics received emphasis:

- A spectrum-efficient weather data uplink system was designed, constructed and flight-tested. Benefits from such systems can include an increase in safety by having real-time weather in convenient graphical form available to the pilot at all times. With data compression as shown by Craig Parker, existing communication or navigation systems may be used to uplink (broadcast) the data.

- Integrated GPS/INS study continued, utilizing the Redundant Strapdown IMU on loan from NASA LaRC. Hybrid and integrated systems will become the norm on all classes of aircraft, and any added knowledge of multi-sensor navigation and guidance systems will prove helpful. GPS and INS are an ideal hybrid pair, as are GPS and Loran-C and other such partners. Increased navigation availability and integrity result.

- The Ridge Regression theory was refined and applied to air navigation scenarios. The extent to which this technique can improve navigation accuracy with only a modest computing load and its comparison with Kalman filters remain active areas of study. If initial promising results are validated, the application of this technique could result in cost savings due to the need for fewer ground emitters. Alternatively, higher availability and integrity numbers could result due to the relaxation permitted in emitter geometries relative to the aircraft.

- System Identification theory was applied to GPS data, to point the way to better understanding of the effects of Selective Availability (S/A) on civilian users of this navigation system. Even differential GPS configuration designers need to consider S/A characteristics in their work.

- JUP meetings provide a forum for reporting on other scientific work of interest to the group. Analysis of thought-related (electroencephalographic) signals for application to control of computer systems could have significance in aid to paraplegics, or for hands-off system control in industrial or air-traffic control areas.

The FAA/NASA Joint University Program is successful and mature because of its stability of sponsor support. The predictable nature of the JUP attracts quality students at all levels, with the assurance that their academic and research activities can be completed without interruption. These students then produce, in partnership with faculty and staff mentors, quality technical products and build the bases for successful careers supporting air transportation.

ANNOTATED BIBLIOGRAPHY OF 1989-90 PUBLICATIONS

1. McFarland, R. H., and Parker, C. B.: Weather Data Dissemination to Aircraft. Proceedings of the AIAA 27th Aerospace Sciences Meeting, AIAA Paper 89-0809, Reno, NV, January 9-12, 1989.

Documentation exists that shows weather to be responsible for approximately 40 percent of all general aviation accidents with fatalities. Weather data products on the ground are becoming more sophisticated and greater in number. Although many of these data are critical to aircraft safety, they currently must be transmitted verbally to aircraft. This process is labor intensive and provides a low rate of information transfer. Consequently, the pilot is often forced to make life-critical decisions based on incomplete and outdated information.

Automated transmission of weather data from the ground to aircraft can provide aircrew with accurate data in near real time. The current National Airspace System Plan calls for such an uplink capability to be provided by the Mode S beacon system data link. Although this system has a very advanced data link capability, it will not be capable of providing adequate weather data to all airspace users in its planned configuration. This paper delineates some of the important weather data uplink system requirements, and describes a system which is capable of meeting these requirements. The proposed system utilizes a run-length coding technique for image data compression and hybrid phase and amplitude modulation techniques for the simultaneous transmission of both voice and weather data on existing aeronautical Very High Frequency (VHF) voice communication channels.

2. Parker, C. B.: A Technique for the Automated Dissemination of Weather Data to Aircraft. Master's Thesis, Ohio University, Department of Electrical and Computer Engineering, Athens, OH, June 1989.

The issue of the provision of weather data products to the aircraft cockpit is addressed. The availability of these data in the cockpit is necessary to allow the pilot to make effective go/no-go decisions when flying in threatening weather conditions. Currently, except for the limited text capabilities of the ARINC Communication Addressing and Reporting System (ACARS), weather data are disseminated by voice communication between aircraft and air traffic control (ATC) personnel. This process severely limits the ability of the pilot and aircrew to obtain timely and accurate weather data.

The transmission of weather data products to the aircraft by data uplink is widely recognized as the solution to the weather data dissemination problem. An analysis is presented in this paper which shows that existing VHF communication systems can simultaneously transmit both analog voice and digital weather data. This hybrid modulation can be accomplished without unacceptable degradation to either communication mode.

An experimental system for the uplink of graphical weather data products is described. This system was developed in order to provide for the evaluation of graphic weather image compression algorithms and cockpit weather displays. Typical compression ratios from 6:1 to 9:1 have been demonstrated. These images have been successfully transmitted in 8 to 12 seconds at 2,400 bits per second.

Finally, it is proposed that the system developed in this thesis be used for the simultaneous transmission of both recorded voice and digital weather data from existing Automatic Terminal Information Service (ATIS) VHF transmitters to the aircraft.

3. Parker, C. B.: 2400 Bit/Second Modem for Audio Channels. Technical Memorandum OU/AEC 30-89TM NASA TRI-U/122, Avionics Engineering Center, Department of ECE, Ohio University, Athens, OH, July 1989.

A transmit and receiver modem pair is described which is capable of transmitting digital data at a data rate of 2400 bits per second over an audio channel.

4. McIntyre, D. S.: Integrated GPS/INS Attitude and Heading Determination. Proceedings of the 2nd International Satellite Division Meeting of the ION, Student Session, Colorado Springs, CO, September 27-29, 1989.

The phase margin requirements of the effective GPS receiver data rate to the guidance loop of the flight control system are discussed. An in-flight attitude and heading algorithm implementing the synergistic benefits of an integrated GPS/INS system is also presented. An optimum approach to the derivation of position and velocity data to obtain aircraft orientation is outlined. In closure, an application of the GPS/INS algorithm to the attitude and heading determination of hypersonic aircraft is presented.

5. McIntyre, D. S.: GPS Effective Data Rate Characterization with Application to Integrated GPS/INS Attitude and Heading Determination. Master's Thesis, Ohio University, Department of Electrical and Computer Engineering, Athens, OH, June 1989.

The integration of the NAVSTAR Global Positioning System (GPS) with the Inertial Navigation System (INS) offers many benefits. INS drift errors may be compensated by the long-term stability of GPS. Conversely, the short-term stability of the INS can be used to correct or substitute for faulty GPS data. Dissimilar redundancy is an additional advantage.

The optimization of the effective GPS data rate is essential for the proper operation of an integrated GPS/INS. This paper develops a transfer function for the GPS receiver. A receiver simulation was developed and tested to determine if the phase response of the transfer function was acceptable for an accurate transmission of attitude and heading information to the flight control system. After the results were interpreted, an integrated GPS/INS algorithm was presented for providing accurate attitude and heading information to a High Speed Civil Transport (HSCT) aircraft guidance control system.

6. van Graas, F., Waid, J. D., and Kline, P. K.: Flight-Test Results for a Prototype Hybrid GPS/LORAN Receiver. Proceedings of the 18th Annual Technical Symposium of the WGA, Hyannis, MA, Oct. 29 - Nov. 1, 1989.

Earth-referenced navigation based on the NAVSTAR Global Positioning System (GPS) and the Long Range Navigation System, LORAN-C, has the potential to satisfy the requirements for a sole means of navigation for the conterminous United States. This paper presents the

design considerations and architecture of a prototype hybrid GPS/LORAN receiver. The receiver is installed in a research aircraft to evaluate the in-flight performance of hybrid GPS/LORAN. The flight-test data is referenced to a differential GPS truth trajectory. Initial test results demonstrate hybrid GPS/LORAN accuracies consistent with current requirements for en route and terminal navigation, and non-precision approaches.

7. Vicksell, F. B., Goddard, R. B., Enge, P. K., and van Graas, F.: Analysis of LORAN-C/GPS Interoperability for Air Navigation. Proceedings of the 18th Annual Technical Symposium of the WGA, Hyannis, MA, Oct. 29 - Nov. 1, 1989.

Computer runs show that it is likely that in the National Airspace System a hybrid of LORAN-C and a 24-satellite Global Positioning System can meet aviation sole means requirements for availability and accuracy, and perhaps integrity as well. A hybrid GPS/LORAN system reduces unavailability by a factor of 1000 compared to GPS alone.

The GPS and the LORAN-C system signals are well suited for combination in a hybrid fix algorithm. Virtual synchronization of GPS and LORAN clocks can be achieved by inclusion of each LORAN transmitter's offset from Universal Time within the LORAN signal. GPS failure rates and distributions of GPS Selective Availability are not yet known, nor are the characteristics of rare high levels of atmospheric noise affecting LORAN measurements known; reasonable estimates were used. An integrity requirement specification would include both a maximum miss rate and a maximum alarm rate along with the radial protection limit. For integrity checking, both the maximum separation and least squares residuals techniques were examined.

8. Kelly, R. J., van Graas, F., and Kuhl, M. R.: Improved Effectiveness of GPS RAIM through Ridge Regression Signal Processing. Proceedings of the 2nd International Satellite Division Meeting of the ION, Colorado Springs, CO, September 27-29, 1989.

A new measurement processing technique is presented which significantly improves the effectiveness of GPS Receiver Autonomous Integrity Monitoring (RAIM). RAIM is a software-based algorithm implemented in a GPS receiver to detect satellite signal failures. The detection of a satellite failure is based on the consistency of a redundant set of pseudorange measurements. GPS positioning requires four satellites to solve for three-dimensional position and clock offset from GPS time. When five satellites are in view, five different sub-solutions can be calculated, each omitting one of the five satellites. If no satellite failures are present, the five sub-solutions will be close to one another. However, if one of the satellites has failed, the sub-solutions will be scattered. The integrity alarm is triggered based on comparisons of the sub-solutions. Unfortunately, a poor distribution of the satellites also causes the sub-solutions to be scattered. Poor geometry, usually expressed in terms of the horizontal dilution of precision (HDOP), frequently exists for some sub-solutions, thus limiting the availability of RAIM. As the HDOP increases, position errors are correspondingly inflated.

In 1970, Hoerl and Kennard developed Ridge Regression to combat near collinearity when it arises in the predictor matrix of a linear regression model. Since a nearly collinear predictor matrix is directly related to a large HDOP, Ridge Regression processing can be applied to reduce the effect of the HDOP, thus permitting GPS to work. It is also shown that the effects of near collinearity cannot be reduced by choosing the estimator error covariance matrix Q_0

such that the innovations of the Kalman filter are minimized. However, a methodology for selecting Q_0 is presented which incorporates Ridge Regression into the Kalman filter. Finally, a computer simulation is implemented to illustrate the improved availability of GPS RAIM by using Ridge Regression processing to reduce those sub-solution errors due to a high HDOP.

9. Braasch, M. S.: A Signal Model for the NAVSTAR Global Positioning System. Proceedings of the 2nd International Satellite Division Meeting of the ION, Student Session, Colorado Springs, CO, September 27-29, 1989.

As the development of the NAVSTAR Global Positioning System (GPS) continues, there will increasingly be the need for a software-centered signal model. This model must accurately generate the observed pseudorange which would typically be encountered. The observed pseudorange varies from the true geometric (slant) range due to range measurement errors. Errors in the range measurements stem from a variety of hardware and environment factors. These errors are classified as either deterministic or random and, where appropriate, their models are summarized. Of particular interest is the model for Selective Availability (S/A) which was derived from actual GPS data. The procedure for the determination of this model, known as System Identification Theory, is briefly outlined. The synthesis of these error sources into the final signal model is given along with simulation results.