CLOSED-LOOP TRACKING SYSTEM PROVIDES REFERENCE FOR DATA COLLECTION EXERCISES

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ABSTRACT

A computational system was developed to support data collection for advanced airborne technology research. Basic research is conducted using a variety of sensing devices for collection of flight characteristics data from aircraft. To maximize control over as many variables as possible during research activities, a controlled aircraft tracking environment is needed to provide reference data for real-time operation and post-mission analysis. The solution to this requirement is realized with the ACMI Interface System (ACINTS). The ACINTS extracts real-time tracking data from a closed-loop telemetered tracking array, reprocesses needed parameters, provides reference data (positioning and control commands) to the sensor device, and records aircraft kinematics for later correlation with other collected data.

KEY WORDS

Closed-Loop Telemetry System
Real-Time Tracking

INTRODUCTION

Considerable attention has been focused on the collection of aircraft flight characteristics data in recent years. This recent attention originates from an interest in how aircraft appear to external sensing devices rather than on how on-board avionics systems characterize the aircraft. To support high fidelity kinematic measurement studies, an alternate method of extracting and recording in-flight data must be developed. Further, a method to correlate collected data with some sort of reference, or truth data is required so that system throughput is accounted for.

Since the early 1970's, the Air Combat Maneuvering Range (ACMR), Air Combat Maneuvering Instrumentation (ACMI), Tactical Aircrew Combat Training Systems (TACTS), and Measurement and Debriefing Systems (MDS) have proven to be reliable sources of closed-loop tracking data for maneuvering aircraft.

These closed-loop systems consist of a series of ground-based relay stations and computational suites working in concert with an Airborne Instrumentation Subsystem (AIS) package on the aircraft. The systems employ a customized telemetering format for all ranging, data transfer, and system calibration functions. The closed-loop tracking function provides state vector outputs from a ten state Kalman filter (X, Y, and Z position; X, Y, and Z velocity; A, B, C, and D Euler angles) that define the orientation of AIS-equipped aircraft. The computational suite operates on downlink messages, passed via the ground-based relay stations, to resolve the aircraft center-of-gravity (CG) kinematics relative to a tangent plane coordinate system. The tracking function is augmented by weapons processing functions that are realistic in every aspect, except that weapons employment is simulated by the computational system.

PROBLEM

This closed-loop tracking system architecture is adequate for its design purpose of aircrew training or system testing and analysis; however, much of the enormous volume of data generated by these systems is lost. Although kinematic data are recorded during each event for later replay and review, tapes are degaussed and reused for later missions.

If retained, these data could be used to support several initiatives. Some major applications include analysis of airborne vehicles by radars or other devices; collection, categorization, and cataloging of air vehicle kinematic characteristics; and development of an Artificial Intelligence (AI) data base for airborne vehicle identification.

A different method must be used to extract and resolve the spatial relationships between in-flight aircraft and external data collection systems. These external systems, or "Sensor Suites" may be used to collect data not normally available on the ACMI/TACTS/MDS, and may also require some assistance in pointing its data acquisition device. Such data collection systems might be cinetheodolites, laser trackers, and video cameras.

REQUIREMENTS

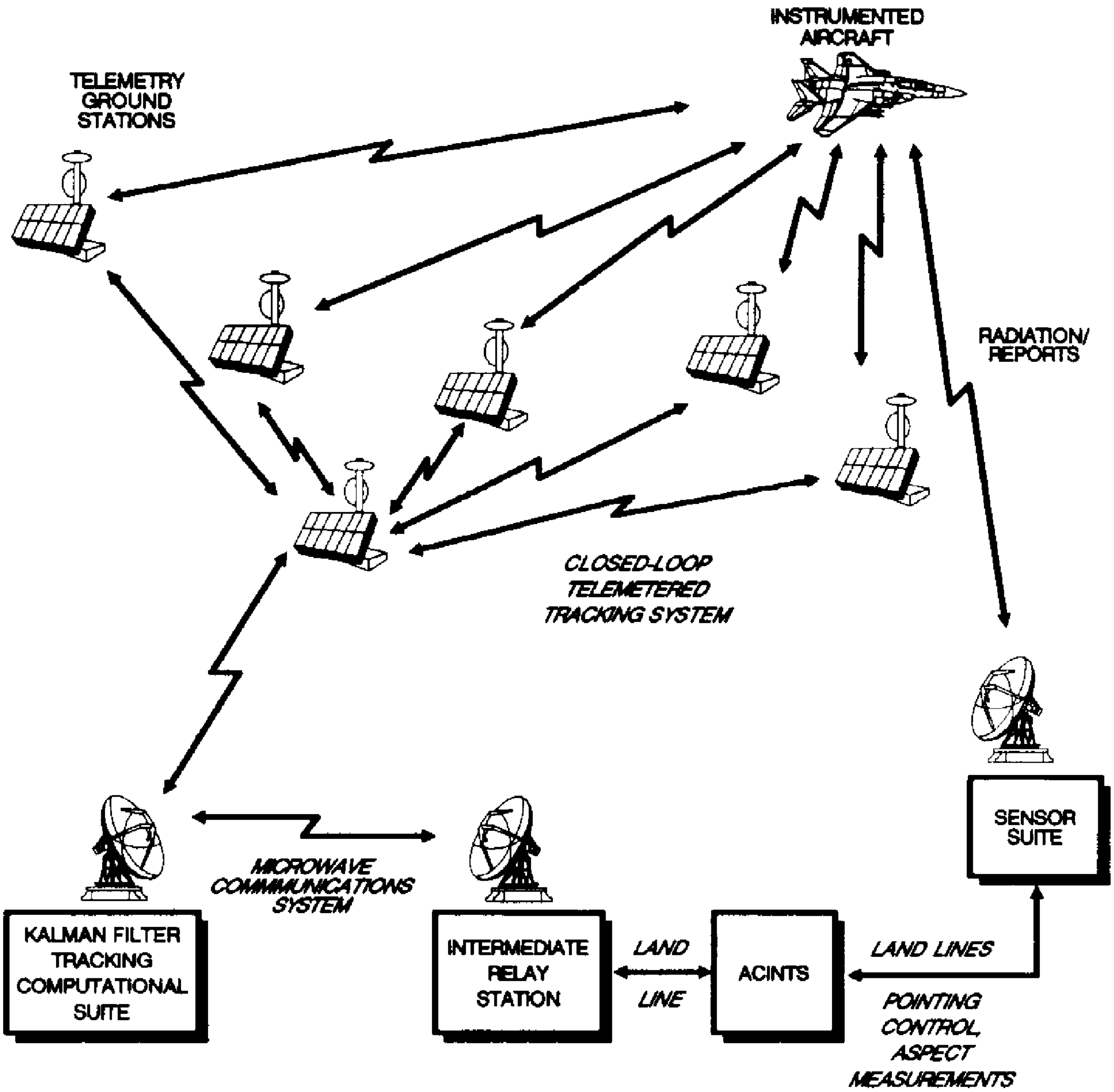
An interface system that can extract the closed-loop system tracking data from the ACMI/TACTS/MDS and reconstitute the data into a more suitable format for a given application is needed to assist sensor suites in the data collection process. Several requirements must be met. First, the system must be able to physically and logically interface to each range tracking system. The host processor must be sufficiently fast to maintain synchronization with the tracking system, and to sustain internal interrupt handling routines. The user interface must provide dynamic activation, control, calibration, and shutdown capability. Data recording must capture incoming digital data from on-range aircraft, or from the tracking system itself. Finally, ACMI, TACTS, and MDS installations are located throughout the world; therefore, the system must be deployable to any of these system locations. These requirements can be satisfied with the ACMI Interface System (ACINTS, pronounced “A-CENTS”).

The first ACINTS was developed by Cyberdynarnics Incorporated under subcontract to General Dynamics Pomona division, and came on line at the Tyndall Air Force Base ACMI in 1987. Since that time, Veda has worked in conjunction with the Air Force to implement system-wide improvements to the ACINTS, and to provide additional growth capabilities. In particular, the capability to interface to multiple generic sensor suites was identified as a future requirement. The need to select tracks from a potential list of 36 or more aircraft was required to support the more advanced RFMDS range, a feature the first ACINTS was not capable of. Veda solved this requirement with an upgraded computational suite with room for growth beyond its present capabilities.

The remainder of this paper discusses the Nellis Air Force Base installation, which was brought on line in March 1992. A second ACINTS derivative which allows networking of multiple sensor suites via a fiber optic network is planned for installation at the Tyndall Air Force Base complex in the near future.

ACINTS FUNCTIONAL CHARACTERISTICS

The ACINTS’ computational suite provides relative position information from a fixed (“Earth stable”) point to an aircraft instrumented with an Airborne Instrumentation Subsystem (AIS) used on the range complex. Kinematic data are extracted from the range system, reprocessed by ACINTS, and transmitted to the sensor suite host to control a secondary pointing device such as a radar or other data acquisition equipment. The ACINTS interfaces to the other data acquisition/collection systems and to system/user terminals. The ACINTS host processor suite is capable of communicating with the RFMDS or ACMI via a customized message protocol. The types of messages sent from the MDS or ACMI include exercise data, maneuver data, filter output data. and range time



ACINTS System Concept Diagram

messages. At the ACINTS user console, the operator can bring ACINTS on line with the RFMDS (or ACMI) and receive messages to support pointing and aspect calculations for the specific data acquisition/collection site and the selected aircraft. The user interface provides a dynamic target selection method and the capability to observe on-range activities.

ACINTS ARCHITECTURE

Central (Host) Processor

The ACINTS hardware architecture consists of a VME bus based multiprocessor system developed by Modular Computer Corporation (MODCOMP), connected to the range system via custom-built interface components. ACINTS features high performance, real-time processing power, and high-throughput I/O subsystems. The ACINTS is modular in design, provides room for future growth, and incorporates hardware interfaces to accommodate differing range geometries and instrumentation configurations.

A single host processor board with a Motorola 88100 Reduced Instruction Set Computer (RISC) CPU run the real-time UNIX operating system along with C applications software. The host CPU board shares the VME system bus with additional processors such as a Small Computer System Interface (SCSI) controller, Ethernet board, serial I/O data distribution boards, and custom message traffic handling from the range system. This configuration allows extremely high speed data transfer without interruption of ACINTS interface I/O channels by external data collection systems. The memory hierarchy consists of a local shared memory system with data distributed to shared memory locations that allow multiple processes to access tracking data at high sampling rates. At the top of the hierarchy, access to CPU memory by external boards (Ethernet, SCSI) is realized via the VME system bus. To minimize delays and I/O bottlenecks, unique memory addressing prevents mishandling data extracted from various boards in the system. Timing critical functions are executed from local memory and passed to other processor and/or I/O boards via VME bus transfers.

Software Environment

The ACINTS software environment consists of MODCOMP's version of real-time UNIX, REAL/IX. REAL/IX is an AT&T UNIX System V source tree derivative. To keep pace with the demands of high data rate tracking information, the ACINTS application takes advantage of the REAL/IX fully preemptive UNIX kernel. This allows any high priority interrupt (i.e. incoming ranging data, exercise data updates, etc.) to schedule and utilize the CPU during operation.

All primary application software is written using the MODCOMP General Language System (GLS) C compiler. GLS C is a full ANSI C X3J11 compliant compiler which prevents use of non-compliant constructs in modules. ACINTS software functions are separated into five major functional entities or Computer Software Configuration Items (CSCIs): 1) ACINTS Control, 2) Range Interface, 3) Sensor Suite Interface, 4) Recording Handler, and5) Display/User Interface.

ACINTS Control

Overall ACINTS control is assigned to the portion of the application that oversees incoming tracking data, recording, aircraft selection, and bus access arbitration via interfaces to the range, display/user, recording, and sensor suite handing routines. The control function maintains the ACINTS and sensor suite calibration data via a central configuration file, which is accessed during system setup, operation, calibration, and modification. The control function prevents out-of-bounds operations on parameters passed between the various ACINTS tasks, including erroneous user inputs such as entry of real numbers into integer fields during calibration, or entering out-of-bounds calibration data.

Range Interface

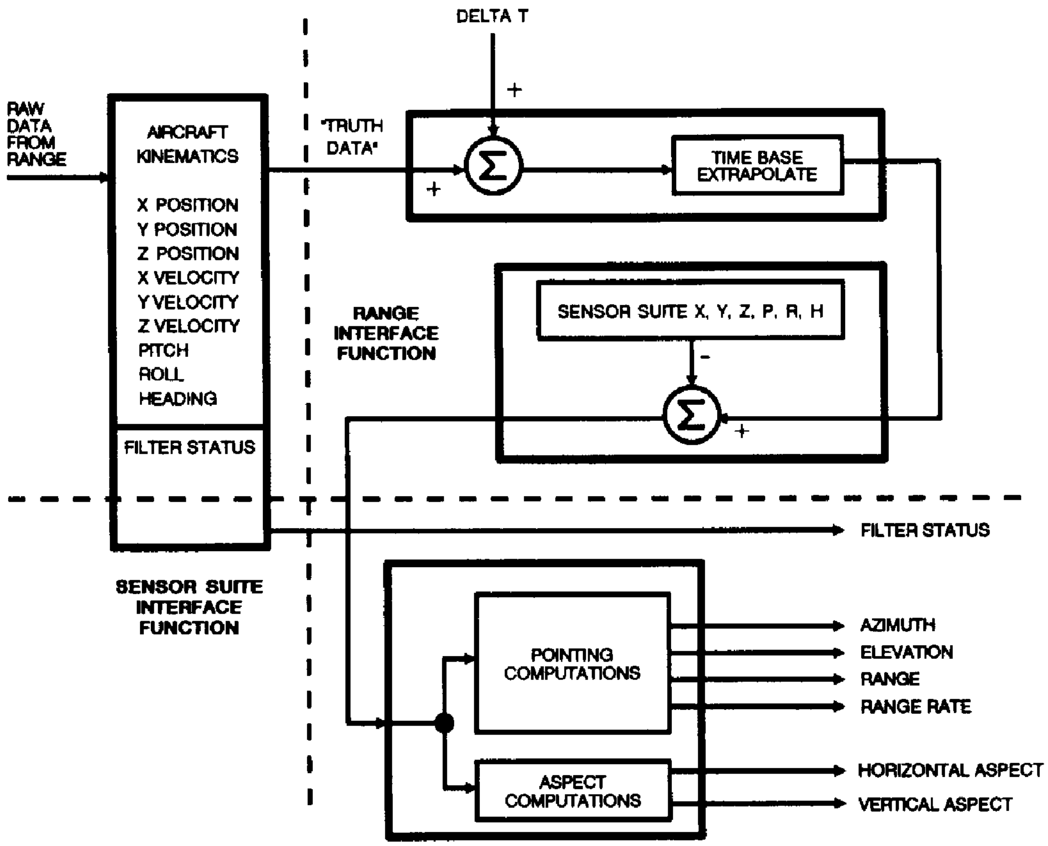
The range interface function establishes a communication protocol with the Nellis Range Support System (NRSS). The NRSS is a link, spur, and hub microwave communication complex that provides data transfer between Nellis Air Force Base and the Nellis range complex. Tracking data are passed to the ACINTS via NRSS. Basic tracking data are displayed on the ACINTS user console as a reference for aircraft selection during data collection and flight observation. The range interface function performs validity checks on incoming data to ensure data integrity.

Sensor Suite Interface

The sensor suite interface function oversees the data communication between the ACINTS and the tracker/controller processor of each sensor suite. Once incoming tracking data are received, the sensor suite interface function resolves the spatial relationship between the sensor suite and the on-range aircraft. Pointing data are formatted and passed to the sensor suite tracker port via an RS-232 interface. The data path is simplex, leaving the sensor suite processor to further determine the validity of pointing data.

Recording Handler

The recording handier monitors the display/user interface to determine if recording has been activated. If activated, incoming tracking data (X, Y, Z position/velocity, airspeed, etc.) are recorded to a high density 8 mm tape cartridge for long term archiving. As old tracks are deselected and new ones selected, the recording handler writes end of file markers and updates the general aircraft data (aircraft type, number, mission name, etc.).



ACINTS Data Flow Diagram

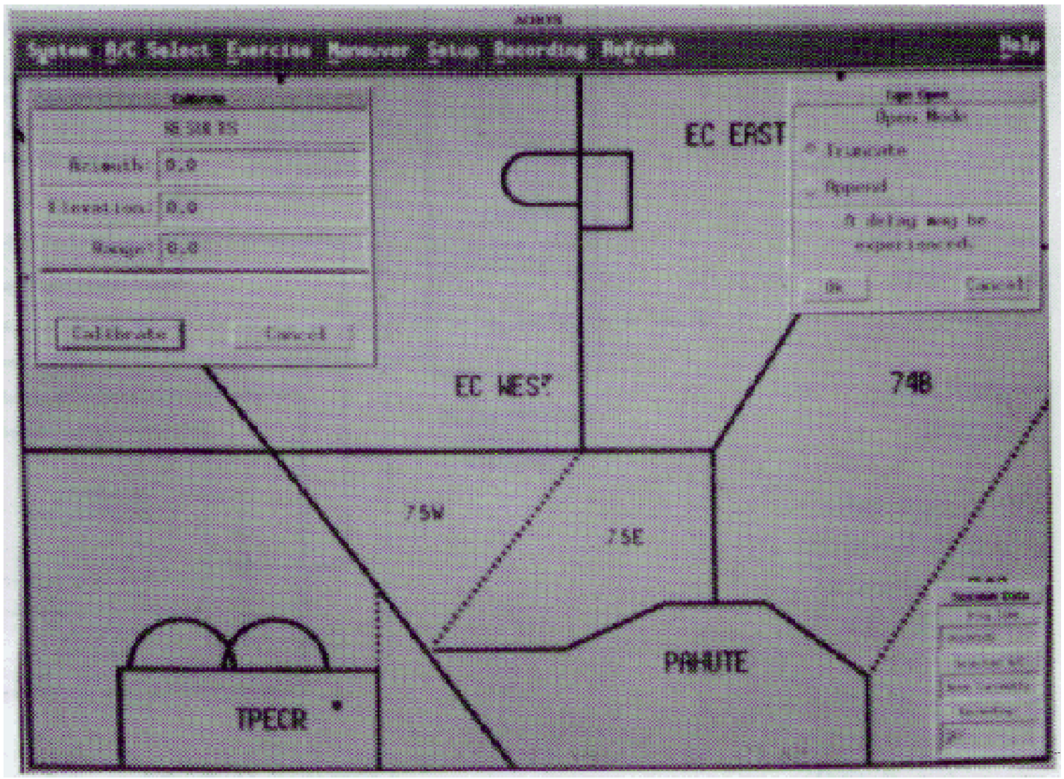
The recording function is an extremely important part of the ACINTS usefulness, as recorded data from both the sensor suites and ACINTS are time correlated and compared to verify the "correctness" of received data (reports returned to sensor suite data collection equipment). Time stamping of received inputs serve as editing tools to factor out inherent system latencies.

Using high density 8mm tape condenses the physical volume of recorded data considerably. With a single tape capacity of 2.5 GBytes and a record length/frequency of 680 bytes/second, over 1000 hours of flight time can be recorded to a single tape (factoring out tape blocking overhead).

Display/User Interface

The display/user interface provides the primary window to ACINTS. By employing an X-terminal/OSF Motif environment, all ACINTS control and monitoring functions are performed here. A 900 square mile God's eye view of the range area is generated to provide a reference to observe on-range aircraft positions relative to the sensor suite. A series of pulldown menus and dialogue/information boxes provide the user with selection and control of ACINTS functions. System health checks are performed by the host. Status changes or error conditions are transmitted across the local area network to the user terminal for further operator action or acknowledgement.

All essential control functions are executed at the main display. They include system shutdown, aircraft select/deselect, exercise data display/request, maneuver data (tracking kinematics) display, system setup, calibration, and recording.



OSF/Motif Provides a Dynamic User Interface

Timing Control and Referencing

Real-time tracking systems typically rely on computationally intensive algorithms to resolve three dimensional spatial relationships between two or more vehicles. Rotational translations are performed to resolve aircraft positions and aspects relative to the data collection system. These computations are highly optimized to keep execution time to an absolute minimum. One major time cycle for RFMDS is 100 milliseconds. All spatial relationship calculations must be completed within this period.

Timing and throughput analyses were conducted during ACINTS development. The results of these tests indicate that all processing and I/O are accomplished well within a 100 millisecond major cycle demarcation. The most time consuming task is data input from the Modular Instrumentation Package (MIP), an on-range interface between the MDS and

ACINTS. These input functions consume approximately 62% of the required processing time, leaving 38% of available processing time for rotational translation, pointing angle and aspect calculation, and sensor suite port I/O.

Establishing Reference Points

Since each sensor suite tracks ACMI/TACTS/RFMDS instrumented aircraft, operation is predicated on proper orientation in the earth referenced tangent plane coordinate system. The ACINTS application software accounts for the sensor suite orientation in X, Y, and Z position as well as pitch, roll, and heading. The pitch, roll and heading terms are included in the event that rugged terrain is encountered at the deployment site, and leveling of the pointing device is not possible. This referencing is intended to reduce or eliminate the effects of absolute system biases, biases that can be controlled with careful sensor suite placement and calibration.

To initialize the sensor suite orientation, accurate positional measurement is required so the information can be translated into the local tangent plane system. The most reliable and expedient method to accomplish this task is via the Global Positioning System (GPS). A GPS receiver is used to obtain position fixes (latitude, longitude, elevation/altitude) on the sensor suite. The GPS data are then entered into the range tangent plane system via a conversion routine supplied from the range central computer. This routine converts the entered positional data into tangent plane X, Y, and Z values. These values are then entered into the ACINTS sensor suite configuration file for use during operations.

Monitoring Tracking Quality

Tracking truth data originates from a closed-loop system and is passed to ACINTS for further processing. While some measure of correction (i.e. smoothing, filtering, etc.) is possible, excessive data manipulation can degrade system performance due to induced system throughput. The reference system (ACMI, TACTS, or RFMDS) monitors the tracking filter performance and reports that performance via the ITRACE indicator. ITRACE tells the system exactly how well or poorly the tracking filter is performing, thus providing a measure of quality of the track data being passed to ACINTS. As tracking quality degrades due to increased Geometric Dilution of Precision (GDOP), loss of line-of-sight (LOS) to ground stations, and/or reliance on other forms of positioning, it follows that ACINTS will respond accordingly.

Time Correlation for Data Analysis

System throughput will induce some measure of latency in the tracking data. This is simply a matter of the physical distances that separate the various subsystems as well as the required processing time at each subsystem. Therefore, differences between the time that tracking data are first received and the time that aircraft kinematics are observed are expected. Two IRIG-B reference clocks, originating from different locations are used, thereby creating a constant time delta between the two sources. The first timing source comes from the RFMDS itself, since each packet of tracking data is time stamped just prior to being transmitted across the NRSS. The second timing source comes from the sensor suite, which provides IRIG-B time from a local IRIG receiver and time code generator/translator. The recording function provides a correlation path between these two times by providing time stamps for both events.

To account for track latency during conduct of a mission profile, a linear time extrapolation term can be entered at the ACINTS console. This feature benefits system performance by providing a measure of control over incoming filtered data just prior to execution of the pointing and aspect algorithms.

The ACINTS obtains reference time via the sensor suite IRIG receiver. When an aircraft track is selected, and recording is enabled, incoming tracking packets, time stamped with the RFMDS range time, are time stamped again by ACINTS. The result is a constant delta time factor captured for later editing. The time difference is between the aircraft measurement time by RFMDS and the time a report (or radar return) for the selected aircraft was received by the sensor suite. During post-mission processing, this time delta can be used to extrapolate out finite errors introduced in resolving the aircraft's actual state vector at the time of measurement.

PERFORMANCE CHARACTERISTICS

The ACINTS was installed at the Nellis AFB complex during the period of 24 through 27 March 1992. The first operations were conducted with no data collected on any aircraft. When ACINTS came on line, aircraft of opportunity were selected and monitoring via video camera observed. The ACINTS controlled the monitoring process for a single aircraft through various maneuvers at ranges from inside ten nautical miles to beyond 25 miles range. The system tracking accuracy was estimated to be within plus or minus 0.2 degrees at 25 miles.

Three operational considerations are in order: absolute system biases, RFMDS track quality, and track latency/time extrapolation.

Absolute System Biases

In comparing the first day tracking exercises against the third day, it can be concluded that some absolute biases are present based on initial positioning. This can be accounted for in several ways. First, position calibration is dependent on the accuracy of the surveyed points used to calibrate the sensor suite position. To complicate the process, the sensor suite is surveyed in using GPS. Even with the best accuracies, some GPS positioning error is still present. This was verified by taking several readings for sensor suite GPS position over the course of the week. Observed offsets were as far as 100 (or more) feet in X and Y, and upwards of 200 feet in Z. Careful, methodical calibration is required to account for this error and to insure that position biases are factored out.

RFMDS Track Quality

ACINTS track quality is affected whenever a tracked aircraft executes a high-rate maneuver. ACINTS relies on RFMDS tracking data, and maintains tracking based on the RFMDS tracking filter performance. The ITRACE value, a measure of RFMDS track quality, must be monitored regularly to correlate what is expected during tracking exercises and what is achievable. The RFMDS is a ground-based closed-loop tracking system that exhibits a geometric dilution of precision (GDOP) as the number of tracking closed loops decreases. This occurs on a regular basis at Red Flag due to the fact that many exercises are conducted at low level flight and high velocities, and lose sight of some of the on-range tracking stations.

Track Latency/Time Extrapolation

During ACINTS controlled or assisted tracking periods, some latency is observed in the system’s performance. When the track is proceeding on a generally straight and level profile, a constant lead or lag is observed in the video display. On the other hand, when the track moves through a more dynamic maneuver, the lead (or lag) becomes more exaggerated. This is exacerbated by the RFMDS tracking quality, as mentioned above, but it is also undetermined whether the ACINTS pointing algorithms induce more latency. In an attempt to account for this, we recorded flight data for a selected aircraft and then compared the IRIG time with RFMDS time as recorded to ACINTS tape. The result is that a data latency of between 120 and 220 milliseconds was observed. Calculating the arithmetic mean of several samples indicated that a 190 millisecond extrapolation factor (Delta-T) was needed to account for this latency. When this Delta-T factor was inserted into ACINTS and aircraft re-tracked, no discernable difference in the tracking behavior was noted. Further observation/analysis is in order.

CONCLUSION

The ACINTS represents an extension of the reliable ACMI/TACTS/MDS. Using this long established tracking process, aircraft kinematics can be cataloged for long-term study and characterization. Ultimately, the knowledge base compiled from these data collection systems could be used to support classification of aircraft types based on measurements taken by sensor devices such as optical trackers, and advanced radars. The ACINTS recording capability prevents the loss of volumes of valuable data that could be applied to other forms of analyses.