Global Positioning System (GPS) Receiver Autonomous Integrity Monitoring (RAIM) Web Service to Support Area Navigation (RNAV) Flight Planning

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BIOGRAPHY

Chris Dufresne is a Computer Engineer with the Volpe Center's Advanced Surveillance and Communications Division (RTV-4A). He joined the Volpe Center full time in June 2005 after spending three years as a student trainee. He received his Bachelor of Science in Computer Engineering as well as a Minor in Computer Science from Northeastern, University, Boston, MA. He has worked extensively on integrating the Volpe Center's GPS and Wide Area Augmentation System (WAAS) Service Volume Models (SVM) with several different domestic and international systems.

Dr. Hansen supports the Surveillance and Assessment Division at the Volpe National Transportation Systems center in the area of satellite and terrestrial navigation systems. In particular his experience in the design and implementation of Global Navigation Satellite System (GNSS) services and applications provide direct domain knowledge to the DOT's efforts on U.S. and international navigation projects. He received his PhD from Stanford University and is a member of the Institute of Electrical and Electronic Engineers (IEEE), the Institute of Navigation (ION), and the Society for Computer Simulation (SCS)

Kevin O'Neill is an Information Technology (IT) Specialist, with the Volpe Center's Aviation Infrastructure Division. He joined the Volpe Center in June of 1999 after working as a contractor to the Volpe Center for the preceding nine years. Kevin has worked in the data communications field since earning a Bachelor of Science degree in Computer Engineering from Suffolk University, Boston, MA in 1988. He is also a Certified Information Systems Security Professional (CISSP). For the last five years he has led the Network and System Administration team responsible for maintaining and monitoring the Federal Aviation Administration's (FAA) Telecommunications Information Management System (TIMS).

Jon Parmet received his B.S in Computer Science from the University of Rhode Island in 1987. His career at the Volpe National Transportation Systems Center began in 1993. His main focus is in the design, development and integration of operational GPS RAIM Availability Prediction systems for the FAA, USAF and several international aviation authorities.

Lou Volchansky works in the Federal Aviation Administration, Aircraft Certification Service, Aircraft Engineering Division, Avionic Systems Branch (AIR-130). Among other duties, he drafts airworthiness criteria for area navigation and Required Navigation Performance technologies. Prior to coming to the FAA in 2002, he spent twenty-years in the Air Force, retiring as a command pilot with over 3500 hours from flying KC-135 and Boeing 707 aircraft as well as the Lear 35. He holds ATP and CFI certificates, and is married with two teenagers.

ABSTRACT

The Volpe Center designed, implemented, and deployed a Global Positioning System (GPS) Receiver Autonomous Integrity Monitoring (RAIM) prediction system in the mid 1990s to support both Air Force and Federal Aviation Administration (FAA) use of TSO C129 receivers. That system is currently hosted at the U.S. NOTAM Office at the Air Traffic Control System Command Center (ATSCC) in Herndon, VA. The system is used to predict TSO C129 GPS RAIM availability for non-precision approach (NPA) operations for a group of military and civilian airfields. GPS RAIM outages for military airfields are available as M-Series NOTAMs and for

civilian airfields. They are available as aeronautical information from Automated Flight Service Stations.

Advisory Circular (AC) 90-100A, published March 1, 2007, requires that a pilot check GPS RAIM availability for Area Navigation (RNAV) routes, departures, and arrivals if RNAV compliance is based solely on TSO C129 equipment [1]. Previously, TSO C129 GPS RAIM availability predictions for the en route and terminal phases of flight were not available. The FAA requested that the Volpe Center develop a web-based TSO C129 GPS RAIM prediction capability in order to provide en route and terminal predictions to the general public. The status of en route and terminal GPS availability is graphically displayed on the web site www.raimprediction.net. This web site is hosted at the Volpe Center in Cambridge, Massachusetts.

This paper describes, in five sections, the design and uses of the AC 90-100A GPS RAIM prediction website. First, the paper addresses the requirements of AC 90-100A, and whom it affects. Second, the paper describes the overall system architecture. Third, it will further detail of each of the system components, including the GPS RAIM service volume model, the outage database, the web based graphical user interface, and the communication channels between them. Finally, it examines future plans and enhancements for the AC 90-100A GPS RAIM prediction system as a whole.

INTRODUCTION

The Volpe Center was contracted by the FAA in early 2007 to develop a web interface to display RAIM prediction information in support of AC 90-100A (originally AC 90-100). The portion of AC 90-100A most relevant to this paper states that "If TSO-C129 equipment is used to solely satisfy the RNAV requirement, GPS RAIM availability must be confirmed for the intended route of flight (route and time) using current GPS satellite information" [1].

Whereas the Volpe Center had previously deployed RAIM prediction systems, the main challenge was to create a graphical user interface (GUI) that was simple to use yet feature rich. The GUI needed to be publicly available and not require installation or training. That required an Internet and browser based delivery. Some of the things that also needed to be taken into consideration were bandwidth and browser compatibility.

RAIM PREDICTION MODEL

The RAIM prediction model works by first acquiring the most recent almanac. In the event that a new almanac is unavailable, the last acquired almanac will continue to be used for up to one week, as we have discerned that is how long the information is reliably accurate for. A virtual GPS constellation is then constructed in memory. As the constellation is iterated through every minute of the prediction window the horizontal protection limit (HPL) and are calculated for each grid point. If the calculated HPL exceeds the respective alert limit for a particular phase of flight that minute is marked as an outage. The horizontal alert limit (HAL) for each phase of flight can be seen in Table 1. Five continuous minutes of outage are required before the outage is reported.

Table 1 Grid Resolution and HAL

Phase of Flight	Grid Resolution	HAL (Meters)
En Route	1.0º	2 NM
Terminal	0.5º	1 NM
Non-Precision Approach	0.5º	556 Meters

These grid points are defined as all the latitude and longitude points that cover the continental United States (CONUS), Hawaii, and Alaska. The resolution of the grid points depends on the phase of flight as seen in Table 1. It is important to note that the grid points do not construct a rectangle that encompasses CONUS, Hawaii, and Alaska, but rather three separate polygons as seen in Figure 1.

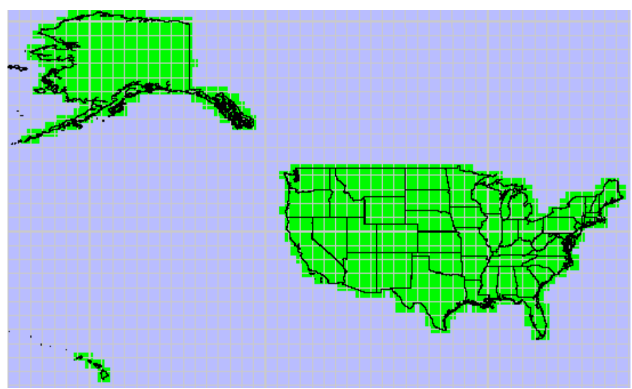

Figure 1 Grid Points (shown in green)

Currently the RAIM prediction model runs at 00:01 Greenwich Mean Time (GMT). The model is set to calculate RAIM availability for a 52-hour period. If, in the time between daily calculations, there is an unscheduled notice to NAVSTAR users (NANU) that affects the current prediction window, a recalculation is performed. However, the next daily calculation will still occur at its usual time.

The Volpe Center has previously deployed its RAIM prediction model to the FAA, Deutsche Flugsicherung of Germany, Air Services Australia, NAV CANADA, and Departmento De Controle De Espaço Aéreo of Brazil. In all cases the model was part of a larger more complex system. It is largely because of this experience that the Volpe Center was able to quickly implement the AC 90-100A website.

CHOOSING THE DELIVERY METHOD

When the different delivery methods were considered, several decisions needed to be made. What information do the users need? How much bandwidth will be needed? How can we convey the necessary information in a way that is simple to understand?

In reference to the first question, we decided the user needed to first know if there were any predicted outages in the next 24 hours. If there were no outages, the user would have fulfilled their obligation. If, however, there was an outage that affected the user, the user needed to know the predicted time period.

We had a limited amount of bandwidth. For this reason we needed a solution that didn't require a lot of back and forth communication between the clients and the server. However, the nature of a GPS RAIM prediction system lends itself to being displayed graphically. So we had to find ways around the bandwidth constraint.

The first idea was to use a series of static images to create an animation. The user could also pause the animation and inspect a single image. If the user clicked on a cell with an outage, a dialog box would pop up with detailed information about the outage. This preliminary idea had small bandwidth requirements and was simple from the user's standpoint; however, it proved difficult to implement because of the many regions of the static images that had to be clickable.

One tool we considered was Google Maps. Google Maps is a Google service offering powerful, user-friendly mapping technology [2]. Google provides an application programming interface (API) that allows people to add features to their mapping software. While this would have saved us time in developing a geographical information system, it would have taken far too much time to fully understand the API and figure out how to integrate all the additional features we wanted to.

We implemented a Java applet, since the Volpe Center had written similar programs in Java for previous projects. This allowed us to make a program that was simple to use yet feature rich and could be run from a web browser without the user having to install it.

GRAPHICAL USER INTERFACE

In developing the GUI there were many things we had to consider. The GUI needed to be intuitive, providing all the necessary information as quickly as possible. We also needed to determine what information was necessary. Through discussions and teleconferences it was determined that users needed a quick summary screen where, if no outages were displayed, they could consider their obligation complete. If there were outages that concerned users, they had to be able to quickly determine the times they would occur. To meet this goal we used a dialog box, as seen in Figure 2, that pops up when the user clicks on an outage.

We took a user centered design approach while developing this application. There was much discussion with various aviation communities that were affected by AC 90-100A. We received a lot of valuable feedback through these channels about how to improve the usability and intuitiveness of the site. For instance, there was originally only the map and no other landmarks to use for reference. Through discussion it was decided that we would add tier 1 airports and capital cities to the map to give the users a reference point when zoomed in close.

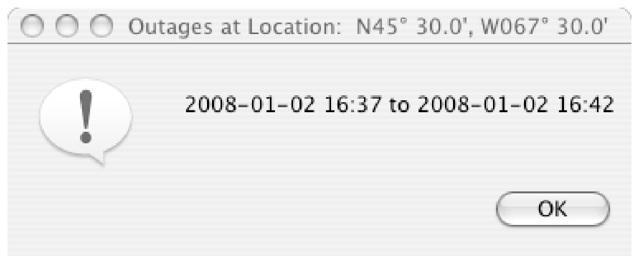

Figure 2 Outage Dialog

Another feature that was requested was a playback option. This would allow a user to watch how the outages moved throughout the day in the form of a movie. One of the questions that needed to be addressed for this feature was whether to use a two or three state logic for the outages. A two state logic would use green for no predicted outages and red if there are any regardless of when they are. A three state logic uses green for no outages, yellow for outages that occur in the future and red for outages that are currently in progress. After much debate it was determined we would go with a three state logic for the playback mode and a two state logic for the summary mode of the applet. The differences between the two and three state logic can be seen in Figure 3 and Figure 4.

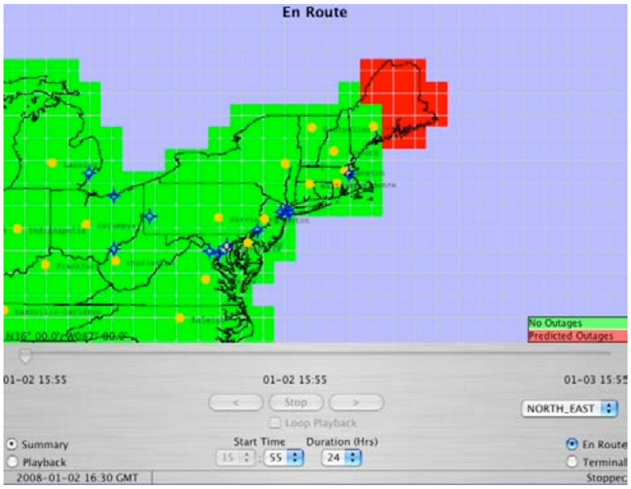

Figure 3 Two State Logic

For the first release only the En Route and Terminal phases of flight were made available to the user. After initial release user feedback indicated that when the map was all green it was difficult to determine if the applet actually changed between the two modes because the change was too subtle. This led us to flash the mode at the top of the map a few times before leaving it solid.

One of the important decisions we made was how to represent the grid because of the resolution limits. When there is an outage at N42° 00.0' latitude W70° 00.0' longitude with 1° resolution, what do you color red? Do you center the outage at that location or do you make that point the upper left hand corner of the cell? We believe it makes more intuitive sense if that point is the center of the outage.

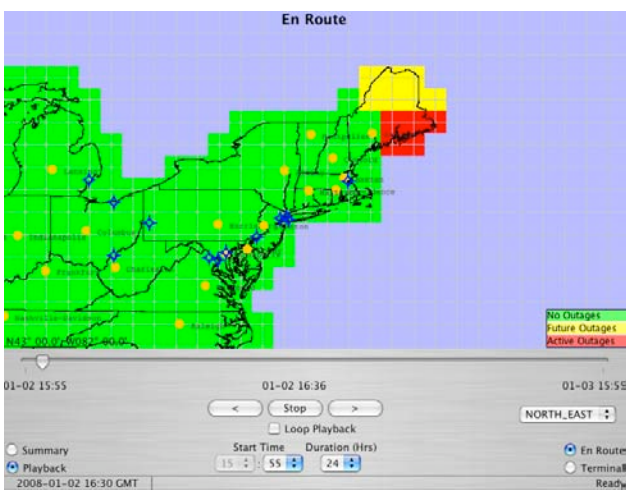

Figure 4 Three State Logic.

Other features that were added include:

- Custom zooming
- Outage details
- Tool-tips for tier one airports
- Adjustable prediction window

DATA FLOW

There are two separate physical computers in our setup. One hosts the RAIM prediction model, while the other hosts the outage database and acts as the web server. This architecture illustrated in Figure 5 allows the web server to continue handling requests without being bogged down during RAIM recalculations.

The RAIM prediction model outputs outage data into a MySQL database. MySQL was chosen because it is open source, scalable, and easy to use. The Volpe Center had used MySQL for previous projects and the familiarity with the software allowed for rapid prototyping. We wrote a custom piece of software that pulled the outage data from the database and created a flat file on the web server.

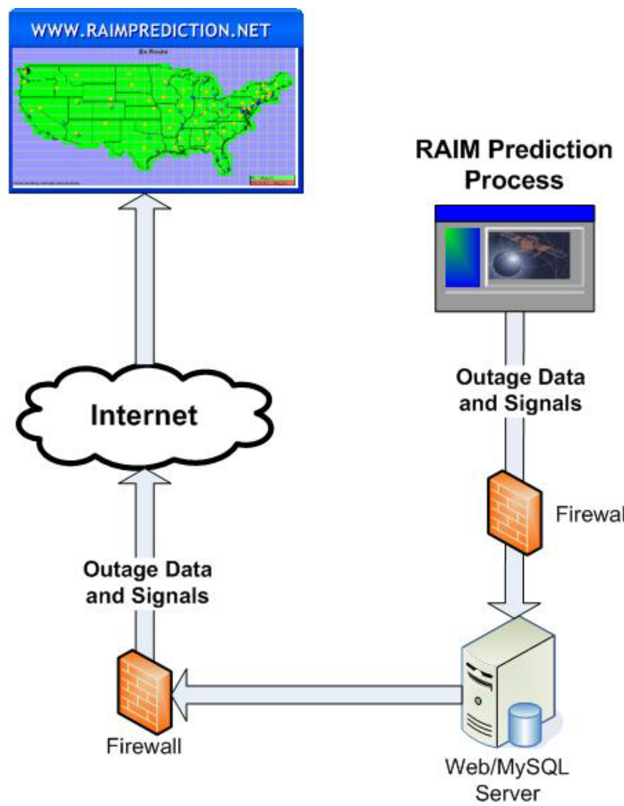

Figure 5 System Architecture

When a user accesses the website, the Java applet is downloaded onto the user's machine and run locally. As the applet is initialized, it retrieves the landmarks, grid points, and outage data from the flat files on the web server. The grid points, landmarks, and outages are then rendered onto the map and the user is free to interact. Anytime the RAIM prediction model is running, a recalculation signal file is placed on the web server. The Java applet periodically looks for the signal file and, if it is found, notifies the user that a recalculation is in progress. This allows the user to make the decision of whether to proceed with current information or wait for the recalculation to finish. Once the recalculation is done, the outages are automatically reloaded.

HIGH VOLUME PLANNING

The type of graphical user interface we built was great for an individual preparing for a single flight or a flight planner with only a dozen or so flights per day. For the high volume planner, operator feedback indicated textual documentation was needed, in addition to claiming the pointing and clicking was too cumbersome. This prompted a decision to accommodate high volume planners (for example dispatchers or flight planning departments). The solution we chose up with was an XML interface. Dispatchers or flight planners would interface with their normal flight planning software. This software would then send an XML request for the route and times in question to our web server. A listening agent on the web server would then signal the RAIM prediction software to spawn a thread and calculate the availability of the route at the times requested.

At the time this paper was published the XML interface was still being designed. The Volpe Center is working with the flight planning industry to develop a single solution that will work for all software manufacturers. Acceptance has been slow as we explain the flight planning procedures listed in AC 90-100A. The flight planning industry appears reluctant to inject change into their software, and it is difficult locating those with the authority to approve the changes.

FUTURE DEVELOPMENTS

The Volpe Center is currently working on adding route of flight capabilities to its software. Route of flight would allow users to select a predefined route and select the estimated times they would be over the waypoints in the route. The software will then color each leg of the route red if there is an outage at the waypoint at either end of the leg or green if there are none.

We are also looking at ways to enhance our GIS features, and overall user interface. There has been a great deal of valuable feedback received and we are working diligently to incorporate those suggestions and improve the user experience. One of the most important enhancements is providing a solution for those without broadband connections. The current solution works well for those with a broadband connection, but is slow for those without one. Another important feature we are working on is detecting the version of the Java runtime environment the user has. Currently the Java applet requires Java 5 or greater. Updating their version of Java has resolved most of the issues users have had with the web site.

Establishing a validation process may be the most important development currently planned. The Volpe Center's GPS RAIM prediction model has been validated numerous times by its various sponsors. As changes are introduced into the prediction algorithm, or the model is deployed on new hardware however, it is good practice to revalidate the model. The Volpe Center and FAA will work in conjunction to validate the outage data provided by the GPS RAIM prediction system. The current plan is to purchase equipment to capture the signal in space. This data will then be compared with what was predicted by the GPS RAIM prediction system.

CONCLUSION

The Volpe Center, in partnership with the FAA, is striving to simplify and automate predictive RAIM flight planning requirements listed in AC 90-100A. AC90-100A requires that a pilot perform a RAIM availability check if TSO-C129 equipment is used to satisfy the RNAV requirement. Pilots are allowed to use the equipment manufacturers RAIM prediction model, contacting a flight service station or using the RAIM prediction website www.raimprediction.net [1]. The FAA and Volpe Center are dedicated to making the website and any related future developments freely available solutions, developed with the user's best interest in mind. The continued support and activism of the user community is vital to making this effort a success.

ACKNOWLEDGMENTS

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2. *What is Google Maps?* http://maps.google.com/support/bin/answer.py?answer=7060&topic=10778