REAL-TIME INTEGRITY MONITORING OF STORED GEO-SPATIAL DATA USING FORWARD-LOOKING REMOTE SENSING TECHNOLOGY

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Abstract

Terrain Awareness and Warning Systems (TAWS) and Synthetic Vision Systems (SVS) provide pilots with displays of stored geo-spatial data (e.g. terrain, obstacles, and/or features). As comprehensive validation is impractical, these databases typically have no quantifiable level of integrity. This lack of a quantifiable integrity level is one of the constraints that has limited certification and operational approval of TAWS/SVS to "advisory-only" systems for civil aviation. Previous work demonstrated the feasibility of using a real-time monitor to bound database integrity by using downward-looking remote sensing technology (i.e. radar altimeters). This paper describes an extension of the integrity monitor concept to include a forward-looking sensor to cover additional classes of terrain database faults and to reduce the exposure time associated with integrity threats. An operational concept is presented that combines established feature extraction techniques with a statistical assessment of similarity measures between the sensed and stored features using principles from classical detection theory. Finally, an implementation is presented that uses existing commercial-off-the-shelf weather radar sensor technology.

Introduction

In an effort to reduce the risk of aviation-related accidents, both the FAA and NASA have sponsored research and development initiatives that seek to demonstrate National Airspace System (NAS) enhancements that will ultimately lead to a safer air transportation system. Technology interventions are being investigated for all of the major accident categories. Specifically, technologies to aid in averting two accident categories: Controlled Flight Into Terrain (CFIT) and Loss of Control in flight (LOC) are focal points of both agency's initiatives. The primary causal factor leading to these CFIT and LOC accidents is loss of situational awareness (SA) by pilots with respect to their spatial location and orientation relative to hazards such as terrain and obstacles. Candidate interventions such as SVS and TAWS seek to improve this aspect of SA.

Synthetic Vision Systems

SVS presents stored geo-spatial data and dynamic real-time data to pilots from an ego-centric perspective (Figure 1). Assuming adequate performance, SVS has the potential to improve safety-of-flight and operational efficiency by enabling pilots to maintain their sense of "vision" with respect to the external environment regardless of the weather conditions.
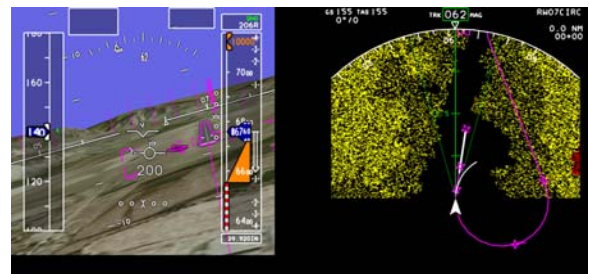

Figure 1. SVS Display Concept

Much of the information to be presented on the SVS does not change significantly over time and therefore, can be stored in geo-spatial databases. This data that is relatively static can represent

terrain; cultural features such as rivers and roads; obstacles such as buildings and towers; and navigation references such as nav-aid locations.

In addition, the SVS display also presents dynamic data, data that does change frequently over time. This data must be obtained in-flight from a sensor, a communication channel, or the crew. Dynamic data includes position; traffic locations; weather; ATC instructions; and flight information services such as Notices to Airmen (NOTAMs). Figure 2 depicts a data abstraction for a notional SVS.
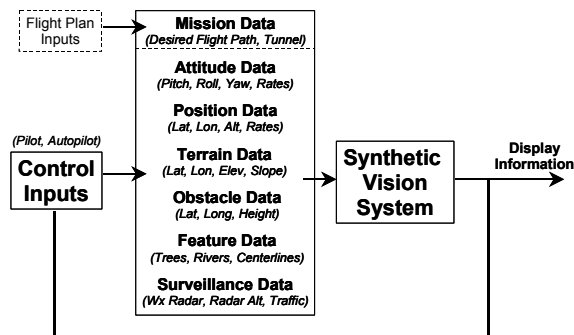

Figure 2. SVS Data Model

Certification and operational approval of SVS for flight-critical applications require a system design that not only assures that the SVS performs its intended functions, but also that it does not provide hazardous misleading information (HMI) to pilots. Quantifiable levels of integrity for each of the data types shown in Figure 2 should be identified. This will determine whether pilots will be able to trust the SVS when they need it most (e.g. in Instrument Meteorological Conditions (IMC)).

Many of the data types shown in Figure 2 may have a level of integrity. For example, attitude information can come from a triple-redundant Inertial Navigation System (INS) instead of a single thread system. Position data can come from a redundant INS coupled with one or more Global Positioning System (GPS) receivers and an augmentation service. In this paper, it is suggested that the proposed monitor is a practical method of guaranteeing a bounded level of integrity for geo-spatial terrain databases.

Integrity

The term integrity is used frequently in the aviation community as a performance metric. Unfortunately, several segments of the community interpret integrity differently. Specifically, there are three definitions of integrity that are relevant to material presented in this paper. For the purposes of this paper, they will be described as system integrity, data integrity, and data processing integrity.

System Integrity. *System integrity refers to the ability of the system to provide timely warnings to users when the system should not be used for its intended function.* This definition is a generalized form of the definition of navigation system integrity where the intended function is navigation [1]. With respect to SVS, these timely warnings must be provided when the probability of providing HMI exceeds a specified bounded value. This value will depend on the operational use of the SVS during a particular phase of flight. Worst-case, it is expected that this value will be of the order of 10^{-9}.

One of the important and unique characteristics of SVS displays is the ability to present a compelling depiction of the external world. It has been suggested that because of the realistic character of the display information, pilots may feel a natural compulsion to trust it. This is a human factor that has yet to be addressed but suggests a need for high-integrity for all of the data types used to support the SVS display functions.

Data Integrity. With respect to geo-spatial databases, required data integrity will depend on (1) the intended use of the data by the pilot and (2) the architecture of the system in which the data resides. One approach to illustrating this concept is to consider multiple levels of data integrity that correspond to its application's criticality (or impact on safety). For example, [2] and [3] delineate five levels of loss of system integrity due to data errors that result in specified failure conditions. Specifically, a loss of data integrity is described as *when data errors could cause or contribute to the failure of a system function resulting in a catastrophic, severe-major/hazardous, major, minor, or no effect failure condition.* These five failure conditions correspond to a range of safety hazards from loss of human life to no effect at all. The hazard level associated with particular data in a

particular system is determined by a Functional Hazard Analysis (FHA).

Data (database) integrity is related to system integrity because of the fact that system integrity can be compromised if data faults/errors exist in the database that can lead to HMI and cannot be detected by the operational system. Three techniques to improve system integrity can be considered in the presence of database errors: *fault-avoidance, fault-tolerance, and fault-detection.*

Fault-avoidance requires a formal validation and verification wherein the designer attempts to prove that there are no database errors that could lead to HMI. *Fault-tolerance* requires that the system be designed to eliminate or mitigate the effects of any latent database errors that could lead to HMI. Typically, redundancy is used to mask the effects of failures that occur during the flight. Lastly, *fault-detection* requires the incorporation of monitor and/or built-in-test equipment (BITE) functions to enable detection of errors in real-time followed by alerting. The effect of the monitor and/or BITE is to lower the probability of an undetected failure, thereby increasing system integrity.

The monitoring approach is the one that is described in this paper. This selection is based on the assumption that geo-spatial terrain databases will contain errors that may provide HMI under certain operational conditions, and that using the other two approaches may be impractical and/or infeasible.

Data Processing Integrity. To ensure that data is not corrupted during processing and/or distribution, requirements for data processing integrity are also important. In [4], data processing integrity is defined as *the degree of assurance that aeronautical data and its value have not been altered since the data origination or an authorized amendment*. Guidelines for data processors and/or distributors are described in [5] that are intended to help ensure that data resulting from processing steps is no worse than the original source data. It is expected that the majority of geo-spatial data that is stored on aircraft, as part of an SVS or TAWS (e.g. terrain data), will not have a stated integrity with respect to the source data itself. The integrity specified with these data will only refer to "data processing" integrity. This is primarily due to the

fact that the amount of validation required to establish and maintain an integrity value for such large data sets is viewed as cost prohibitive.

Integrity Monitor Operational Concept

Historically, various monitoring methods have been used to provide navigation system integrity. In order to attempt to "keep it simple" and avoid a web of ground-based integrity monitors, the proposed monitor implements a form of autonomous integrity monitoring analogous to the Receiver Autonomous Integrity Monitor (RAIM) approach used by GPS. The RAIM concept is based on a consistency check among multiple measurements that are assumed to be independent and uncorrelated [1]. In the case of the proposed method, ranging measurements to geo-spatial locations (e.g. terrain and obstacles) are compared with the expected range to these locations that are derived from the databases.

To determine integrity requirements, there is a need to identify operational situations where an undetected terrain data failure could have a severe-major effect on airplane, crew, and passengers when using SVS. In other words, when can erroneous terrain data threaten the integrity/safety of the flight? Integrity threat models can be used to help answer this question. These models can then be used to support the FHA. FHAs are more general in nature in that many of the hazards described in the FHA are due to detectable failures - not due specifically to integrity failures. To develop integrity threat models for SVS, three classifications of IMC operations are considered: (1) nominal operations; (2) off-nominal operations; and (3) enhanced operations. Operations in Visual Meteorological Conditions (VMC) are not considered as it is assumed that SVS integrity can be assured sufficiently by pilots using visual references in these conditions.

Nominal Operations

This class of operations includes all existing operational situations where the aircraft is following a pre-defined and well-established course or procedure, including appropriate coordination with Air Traffic Control (ATC). During nominal operations, the pilot is either (1) monitoring or engaging autopilot modes, or (2) actively controlling the aircraft using flight-director type

guidance derived from a navigation database. Examples include: coupled ILS approaches and missed approaches that follow a defined missed approach procedure. During nominal operations, SVS will provide guidance to the published (and presumably correct) path using navigation data provided by conventional systems. In the case of SVS, it is expected that this will take the form of a tunnel in combination with flight-director guidance. Supplemental to this guidance symbology will be a depiction of terrain to improve SA. Even though stored terrain data may not be used to locate the tunnel on the display or to compute flight-director guidance, it has been suggested that the compelling nature of the SVS display may introduce HMI during nominal operations if the terrain data has insufficient integrity.

Off-nominal Operations

This class of operations would include unavoidable, inadvertent, and desirable deviations from the existing operational situations described above. These deviations may be *unavoidable* due to lack of engine performance, weather conditions, or on-board emergencies. *Inadvertent* deviations may be due to pilot error (e.g. distracted, VMC pilot in IMC). Finally, these deviation may be *desirable* if pilots deviate to save time and/or fuel for example. For these off-nominal operational modes, if the aircraft is operating near terrain in IMC and has deviated from the tunnel or flight-director, the SVS terrain depiction must be used as a primary navigational aid (analogous to flying under Visual Flight Rules (VFR)). Without an integrity monitor function such as the one proposed, use of SVS during these off-nominal operations could be hazardous.

When performing off-nominal operations such as the ones described, it is anticipated that pilots are more likely to accept less integrity than for the nominal operations (i.e. "any nav-aid is better than no nav-aid"). However, is it of any benefit to give them a terrain display to aid navigation if it has no integrity?

Enhanced Operations

This class of operations includes new operational capabilities that may become feasible if a high-integrity SVS is available on aircraft. For example, it has been suggested that aircraft equipped with SVS may be able to fly with reduced minimums to particular runways. Other examples include: curved approaches; approaches to runways with little or no ground infrastructure (e.g. no ILS); and enabling functions such as dynamically generated path creation and guidance. All of these new operational capabilities can conceivably be accommodated by SVS if adequate integrity can be assured.

Forward-Looking Autonomous Integrity Monitoring (FLAIM)

The proposed integrity monitor uses a forward-looking sensor (Figure 3) to enable consistency checking between sensed and stored geo-spatial terrain data. Unlike previous work that made use of downward-looking radar altimeter (DLRA) measurements [6], the use of a forward-looking sensor is expected to improve the detection of horizontal failures while reducing minimum detectable biases and exposure time. Because the only observable using the DLRA approach is in the vertical direction, horizontal failures must be significant to be "observed" in the vertical measurements. Further, observing horizontal failures also depends on the character of the terrain if only looking down. By using forward-looking measurements, the observability of both vertical and horizontal failures increases.
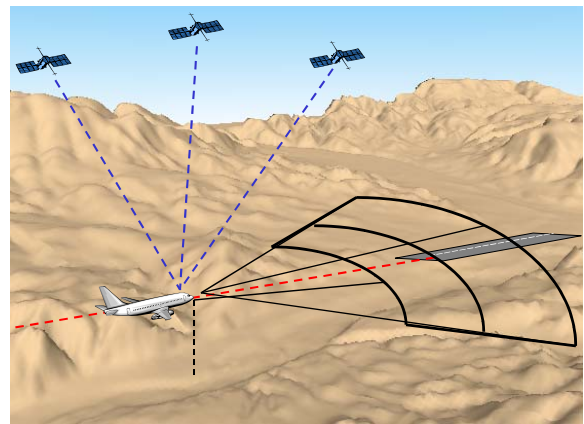

Figure 3. Forward-Looking Monitor Concept

In addition to this technical advantage, there is also an operational advantage to using a forward-looking approach. For TAWS and SVS displays, most of the potential HMI will be "out-in-front" of

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the pilot. By establishing integrity using measurements of the terrain ahead of the aircraft's position, the pilot will have more time to take appropriate action when an integrity violation is detected.

The FLAIM approach is similar to that of RAIM as follows: (1) it performs a consistency check among independent uncorrelated measurements; (2) it assumes that there is redundancy in these measurements; (3) it is based on statistical detection theory; (4) integrity requirements are based on operational use; and (5) it uses past and present measurements. The proposed solution is different from RAIM in the following ways: (1) the term autonomous has a different connotation; (2) the time-to-alarm is based on collision risk; (3) it provides a potential source of positioning integrity, and (4) it is not envisioned as a component of GPS receivers.

The FLAIM approach is "autonomous" in that the monitor would execute in real-time independent of the display processing. The FLAIM approach does not require any ground-based infrastructure to provide a level of integrity. However, if the positioning sensor used by FLAIM (e.g. GPS) requires a ground infrastructure (e.g. an augmentation service), then one cannot say FLAIM would be autonomous in every sense.

Conceptually, FLAIM acts as an intermediary between the source data and the SVS or TAWS display(s). This "watch-dog" type function checks any requested data against an independent source in a statistical manner. When a statistically significant difference is detected, the pilot is informed that the integrity of the displayed information has been degraded. When differences are within expected bounds, the pilot can be assured that the display is operating at its specified performance level with a probability consistent with the level of integrity required for the current operation.

Detection based on statistical disparity results in a non-zero probability of false alarm (a failure is detected when there is no actual failure) and a non-zero probability of missed detection (a failure exists but is not detected). The detection threshold that is chosen will determine these probabilities. Clearly, the challenge is defining an appropriate test statistic for the expected failure modes.

Before describing a specific implementation of FLAIM, the following assumptions are made:

- The integrity of the positioning system (e.g. augmented differential GPS) will be sufficient for operational use and this integrity will be maintained independently of the database.
- Data providers cannot guarantee that there will be no failures in their geo-spatial database products that can result in the presentation of HMI to the pilot.
- Comparing stored geo-spatial data with sensed data increases the probability of detecting failures that could lead to HMI.
- The number of database failures detected can be increased without introducing new failure modes that could lead to HMI.
- Sensor technology already exists that can provide adequate performance and integrity to enable detection of significant mismatches between geo-spatial databases and the measurements. These mismatches will indicate failure modes that exceed a safe threshold.

FLAIM Operational Concept

Consider an operational environment where SVS displays are being used in IMC. During flight, FLAIM will statistically assess the consistency between sensed and stored geo-spatial data. When a prescribed threshold is exceeded, the crew will be notified in time to take appropriate action avoiding a potential incident that may otherwise have been induced by the SVS. These disagreements, or mismatches, will be detected within a prescribed volume in front of the aircraft's flight path vector. Within this volume, four types of situations will occur during the operation with respect to FLAIM.

1. *Match* - sensed and stored geo-spatial data are both correct with respect to their stated quality

2. *Match* - sensed and stored geo-spatial data are both equally incorrect with respect to their stated quality

3. *Mismatch* - sensed data is incorrect with respect to its stated quality

4. *Mismatch* - stored data is incorrect with respect to its stated quality

Type 1 situations would be the nominal case, that is, the SVS is faithfully presenting the scene within the nominal quality specification. Type 2 situations describe database failures that cannot be detected by FLAIM; that is, integrity failures. However, on of the objectives of this work is to prove that the probability of a Type 2 situation occurring is much smaller (maybe even zero) than the probability of an integrity failure occurring without the aid of FLAIM. In Type 3 and 4 situations, FLAIM would warn the pilot that the SVS is operating in a degraded mode and that continued flight along the same trajectory may be hazardous.

It is important to note that the flight crew can, and will, act as another independent integrity monitor of geo-spatial databases. For example, in VMC, pilots may be able to observe gross database failures compared to what they see out the window. However, the performance of a human monitor will be driven by visibility conditions, workload, pilot experience, and other factors such as the amount of available information. As it is difficult to quantify this type of human performance, it is not recommended as a sole means of integrity assurance for stored geo-spatial databases, particularly in IMC.

Sensor Technologies

Many remote sensing technologies have been developed that have the potential to meet the operational requirements of FLAIM. Table 2 lists several along with some of their important characteristics. Notice that only two are currently certified and operating routinely in all weather conditions on civil aircraft: the radar altimeter and the weather radar. Radar altimeters measure height above ground level (AGL) from a rigid-mounted antenna on the belly of aircraft. They are usually triply redundant (3 antennas, 3 transceivers) as they are essential for auto-land systems during flare.

Weather radar antennas typically scan in azimuth from the nose of the aircraft. Some models scan in elevation as well, but typically, the elevation angle is set by the pilot or gimbaled to remain at a fixed tilt angle with respect to local-level. As the name implies, the primary function of weather radars is to provide pilots with an indication of significant weather (moisture) in the area.

However, returns from the ground are also received and displayed when the antenna beam is hitting the ground and ground-clutter suppression is not engaged.

Table 2. Candidate FLAIM Sensors

Sensor	Band (GHz)	Usage	All Wx
Radar/Radio Altimeter	4.2-4.4	Civil/Military	Yes
Weather Radar	8-12	Civil/Military	Yes
Doppler Radar Navigators	13.25-13.40	Military	Yes
Passive/Active mmWave	40-300	Experimental	?
Fwd-Looking Infra-Red	300-1e6	Civil/Military	?
Laser Rangefinder	~300	Military	?
LiDAR	~500	Experimental	?
SAR	Varies	Experimental	?

Although a Forward-Looking Infra-Red (FLIR) system has recently received a Supplemental Type Certificate (STC) for the Gulfstream G-5, use of FLIR technology, in general, is still primarily limited to military and law enforcement aircraft to enable a level of "night vision".

Furthermore, both FLIR and Passive Millimeter Wave (PMW) are passive imaging sensors that do not provide range measurements. Integrity monitoring using these types of sensors would require a pattern-matching capability. Also, high frequency and high-resolution sensors such as FLIR, PMW, Laser, and the more general Light Detection and Ranging (LiDAR) sensors must contend with large attenuation in poor weather conditions. Overcoming these disadvantages may require high-quality, high-sensitivity receivers that may prove costly to implement and certify and still they may have uncertain performance with respect to weather effects. Doppler radar navigation sensors do not provide range measurements directly, but range can be derived if integrated with a positioning system. Synthetic Aperture Radar (SAR) techniques can be applied to various sensors to achieve higher resolution by taking advantage of

aircraft movement and accumulating measurements over time.

In summary, in a perfect world, infinite power would be available and the smallest wavelength could be chosen to get the best accuracy, resolution, and range. Unfortunately, practicality drives the design decision toward the opposite conclusion. Despite this practical constraint of today's technology, the proposed approach can be applied to any sensor technology. To assess the feasibility of the FLAIM approach, a specific implementation is described further that makes use of a commercial weather radar sensor.

FLAIM Using Weather Radar

Although the primary function of weather radar is to measure moisture-related "weather", the radar will also receive echoes from the ground if its antenna is pointed in that direction. Previous work has demonstrated this capability. For example, the technology described in [7] is designed to detect terrain and obstacles and alert the pilot in time to avoid an incident. This is similar to the FLAIM problem, but is strictly a sensing function and as such, does not perform an integrity monitoring function on stored geo-spatial data. More closely related is the technology described in [8] which suggests a database verification capability using a weather radar sensor that interleaves weather measurements with terrain measurements. In [8], a test statistic is defined as the fraction of radar measurements that cannot be explained by other on-board data sources (including the terrain database).

In addition, the Autonomous Precision Approach and Landing System (APALS) technology described [9] was designed to enable precision approaches using stored geo-spatial data and weather radar measurements. APALS accomplishes this by providing position "fixes" for the navigation system during final approach.

Alternatively, for the FLAIM implementation described here, the weather radar equipment is not modified. Minimal configuration changes (e.g. range, scan pattern) may be required from its normal operational mode. No ground components such as reflectors at surveyed locations are required. Further, in order to keep the sensor measurements independent from database-derived "synthetic"

measurements, the terrain database is not used to determine where to point the weather radar. While this "expectation-driven" approach can improve integrity, it is believed that a higher level of integrity can be achieved by keeping the two completely independent.
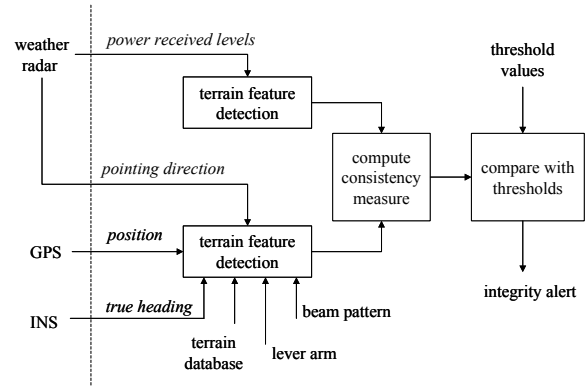

Figure 4. FLAIM Using Weather Radar Sensor

Figure 4 depicts the basic architecture of a FLAIM that uses weather radar measurements to support the in-flight consistency check function. As the weather radar scans in azimuth, radial measurements are generated. Each measurement consists of a reflectivity (or power-received) level at N range bins out to a defined range. Note: As specified in [10], commercial weather radars that are used in civil aviation generate power-received values at a set of quantized levels within each range bin. As the radar antenna scans, these Nx1 vectors (radial lines) are accumulated at M azimuth angles. These radial lines are then input to a feature detection and reduction algorithm.

The feature detection algorithm attempts to segment the M one-dimensional radial lines and classify the segments as one of L feature types. In addition, more than one scan of $M*N$ measurements can be used to increase confidence in certain spatial features.

The terrain database thread in Figure 4 attempts to detect, segment, and classify the same L features to enable a one-to-one comparison between weather radar derived information and terrain database derived information. To do this, additional inputs are required: position, heading, azimuth pointing direction of the weather radar

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antenna, and the terrain database. With this information, computation of the relative location of the terrain database with respect to the aircraft can be computed. The other required input to the terrain database thread is a model of the antenna beam pattern so the illuminated surface area along a particular pointing vector can be computed or estimated (Figure 5).
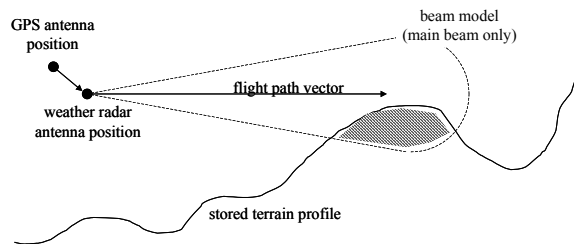

Figure 5. Deriving Synthetic Measurements Using GPS and a Terrain Database

After detection and classification of features for both sensed and database-derived measurements, a consistency measure is determined and evaluated against a preset threshold. If the threshold is exceeded an integrity violation is detected and a visual or aural alert is generated for the pilot.

Feature Detection Preliminary Results

Figure 6 provides a visual representation of the output of both threads of Figure 4 after the segmentation stage. The left plot depicts measurements received during a single scan of the weather radar (+/- 30 degrees in azimuth, zero degrees tilt). The right plot depicts the points in the same coverage area where a modeled main beam hit/pierced the stored terrain database from the perspective of the aircraft position at the same time as the weather image was captured. Both plots were generated using actual flight-test data acquired during the Fall of 2001 onboard a Boeing 757 aircraft in central Colorado.

For this illustration, no feature detection or classification is performed and yet an obvious similarity can be observed between the sensed and database-derived depictions. Note: the

measurements for these plots were taken at an altitude of ~500 feet AGL on final approach.
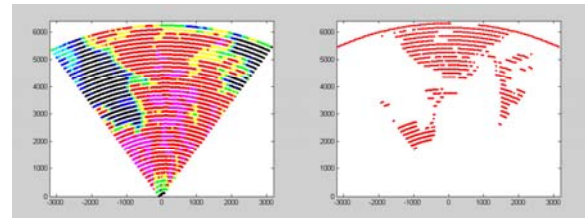

Figure 6. Example of Simple Feature Detection

Unfortunately, the weather radar terrain measurements cannot be mapped to the terrain database entries directly. The feature detection and extraction methods in both threads of Figure 4 are the steps necessary to enable a one-to-one comparison. The feature detection and extraction algorithms convert, or transform, the weather radar measurements and terrain database entries to a common domain (the feature domain) where a one-to-one comparison can be made. For the sensor measurements, development of a robust transformation scheme requires a good understanding of the underlying physics of the weather radar measurement mechanism. Furthermore, by performing feature detection and extraction, computational complexity is reduced, and derivation of a statistical model for disparity can be simplified.

To illustrate, consider the following example using three consecutive scans during the Boeing 757 flight mentioned above. The weather radar in this case was scanning at approximately 40 degrees per second thus covering the +/- 30 degree region three times in about 4.5 seconds. With measurements being taken at 0.25 degree increments, this produced 720 radial lines of $N=42$ range bin measurements. Range bin size was 150 meters. Significant features were detected using a feature detection and extraction algorithm based on shadow regions for both the radar and the synthetic (database-derived) data.

For this example, two feature types are defined (Figure 7). L_1 features are the range bins that represent the leading edge of shadow responses along each radial line. L_2 features are the number

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of range bins that comprise the length of shadow responses along each radial line. Classification of the radial line segments as shadows is determined by the measured response (nominally zero).
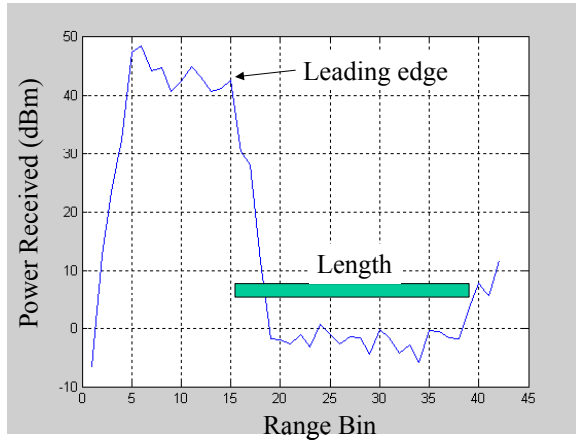

Figure 7. Example of Features Extracted from a Radial Line Measurement

Figure 8 shows the resulting features for three scans from the Colorado flight and compares the agreement of the weather radar-derived features with the database-derived features. The residual for the leading edge feature is shown on the left in Figure 9. The mean-zero behavior is expected for the nominal terrain database (fault-free).
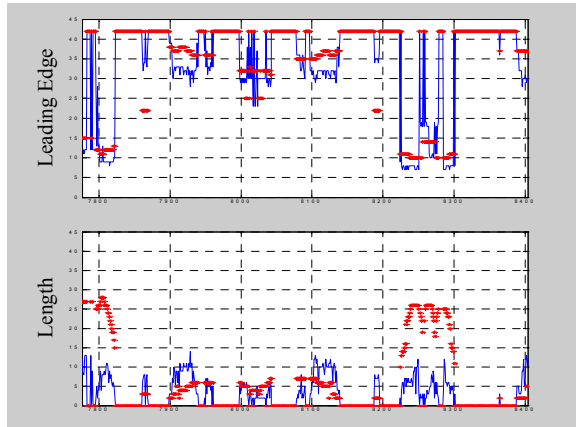

Figure 8. Features Detected During Three Scan Sample (*Database, -Radar)

Finally, a significant failure was inserted into the terrain database: a lateral bias of 1 km. The re-generated residuals (using the same weather radar data) are shown on the right in Figure 9. Notice the

presence of a large bias (18.3 range bins) in our new residuals. This behavior suggests that horizontal database bias can indeed be detected by the proposed approach.
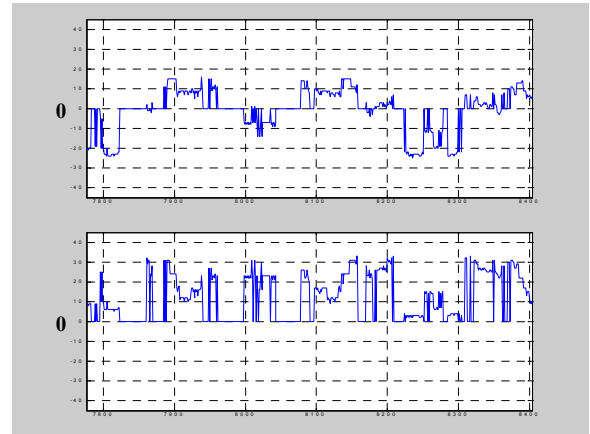

Figure 9. Comparison of Leading Edge Feature Residuals With/Without Database Bias

Status

The research effort outlined in this paper is still in its early stages. Currently, various feature detection and classification schemes are being investigated in preparation for multiple flight tests planned over the next year. For these flight tests, a prototype FLAIM system is being implemented that can be interfaced to both a general-aviation grade weather radar and a high-end state-of-the-art transport-category weather radar. The interface to both weather radars is based on the ARINC 708A protocol [10]. The system will be evaluated during nominal and off-nominal operations with both fault-free and faulty databases.

Once a robust feature detection and classification scheme has been defined, the probability of false alert, the probability of missed detection, and the minimum detectable bias can be related to the fault-free and faulty state of the terrain database and the forward-looking sensor statistics via the necessary transformation functions. Subsequently, using an appropriate test statistic, significant deviations from the fault-free behavior can then be detected to a bounded probability (integrity).

Summary and Conclusions

The design of SVS for flight-critical applications requires a thorough understanding of the failure modes that can occur and result in the presentation of hazardous misleading information to pilots. The technology presented attempts to address those failure modes associated with incorrect terrain databases by providing an in-flight consistency check to ensure integrity.

Terrain data integrity was defined in the expected operational context of SVS and an operational framework for an integrity monitor was established. This monitor is based on using a forward-looking sensor to detect horizontal and vertical database bias with enough time remaining for safe recovery. Initial testing using commercial-off-the-shelf weather radar technology looks promising but the algorithms must be fine-tuned and a statistical model must be derived. This statistical model, based on a rigorous analytical approach, will determine the integrity that can be expected from geo-spatial terrain data used in flight systems in conjunction with the described monitor function.

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