AESS MEETINGS & CONFERENCES

Barry C. Breen, Vice President-Conferences
Iram J. Weinstein, Associate Vice President-Conferences

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<tr>
<td>November 8-10, 2004</td>
<td>IEEE Waveform Diversity &amp; Design 2004</td>
<td>Edinburgh, UK</td>
<td>IEEE-EU Event Services, +44 (0) 1418 766548 +44 (0) 1418 766599 F <a href="mailto:events@iace.org">events@iace.org</a></td>
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<tr>
<td>November 15-17, 2004</td>
<td>Non-Volatile Memory Technology</td>
<td>Orlando, FL</td>
<td>K. Strauss, Karl F <a href="mailto:Straus2@ipfi-mss.gov">Straus2@ipfi-mss.gov</a></td>
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<td>March 2005</td>
<td>Board of Governors Meeting</td>
<td>Big Sky, MT</td>
<td>Society Secretary</td>
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<td>May 9-12, 2005</td>
<td>2005 IEEE Space Confab</td>
<td>Artesia, VA</td>
<td>T. Fagan, (860) 738-7521 1806-539-8617 F <a href="mailto:tfagan@iace.org">tfagan@iace.org</a></td>
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<tr>
<td>May 23-25, 2005</td>
<td>12th International Conference on Integrated Navigation Systems</td>
<td>St. Petersburg, Russia</td>
<td>J. T. Schmidt, (617) 296-3844, <a href="mailto:jtd@agogo.com">jtd@agogo.com</a> <a href="http://www.electrooptics.co.uk">http://www.electrooptics.co.uk</a></td>
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<td>September 18-21, 2006</td>
<td>Autonomous 2006</td>
<td>Artesia, CA</td>
<td>B. Russu, (617) 296-0222 (810) 364-6682 F <a href="mailto:bRussu@asus.com">bRussu@asus.com</a> <a href="http://www.asus.com/">http://www.asus.com/</a></td>
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OTHER SOCIETY MEETINGS OF AESS INTEREST

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<td>November 16-18, 2004</td>
<td>USAF Developmental Test &amp; Evaluation Summit</td>
<td>Woodland Hills, CA</td>
<td><a href="http://www.asa.org/events/OTES/ennett">www.asa.org/events/OTES/ennett</a></td>
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Send all corrections and omissions to Barry C. Breen at his address on the inside back cover.
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In This Issue - Technically

Buried Small Objects Detected by UWB GPR

A ground penetrating radar (GPR) using short-pulse is developed to detect small and shallow metal objects buried underground. A bistatic mode in which the GPR system uses separate transmitting and receiving antennas is applied. A modified fat dipole antenna is developed for the transmitting and receiving antennas. The prototype of the system is tested in the real environment and 2D visualization of raw data is achieved. We show that the developed system has a good ability to detect underground metal objects, and even small targets of several centimeters.

Commercial Technology & Avionics Architecture

As commercial technology has become more embedded in the military community, there have been attendant effects caused by the rapid progress in technology and by obsolescence. Industry has generated many solutions to mitigate these effects, but their limitations are emerging with time. This is a discussion of higher-level approaches to obsolescence solutions and technology insertion problems that have not hitherto been addressed.

Wireless Interconnection to Test Instruments

Manufacturers are increasingly offering Ethernet connectivity on their test instruments. An additional benefit of this connection method is the ease of conversion to wireless connectivity. This paper describes the Ethernet interface used in the remote control of an RF power amplifier and describes the conversion to wireless connection.

Automotive-Grade MEMS Sensors Used for General Aviation

The Attitude Heading Reference System (AHRS) provides data for primary flight instruments, head-up displays, autopilots, and moving map navigation systems. Advances in solid-state MEMS rate sensors, coupled with Kalman Filter algorithms designed to mitigate high drift rates, provide the basis for low-cost, high-performance AHRS for general aviation.

This paper describes the performance of a low cost, miniaturized AHRS using automotive-grade MEMS sensors. The performance of the system is detailed. The implications for certification of this class of system and fault tolerance are discussed.

UWB Implications for Spectrum Management

This paper presents some of the challenges facing the introduction of ultra-wideband (UWB) technology in wireless applications intended for commercial use, summarizes relevant regulatory and standards developments, and addresses potential implications on spectrum management and radio regulations.

Software Intensive Systems Safety Analysis

Two important elements in the avionics suite of modern aircraft are: the Flight Control System (FCS) and the Flight Management System (FMS). The FCS provides the capability to stabilize and control the aircraft, while the FMS is responsible for flight planning and navigation.

A clear trend in the aerospace industry is to place greater reliance on software systems, and many FCS and FMS subsystems are implemented primarily in software. For example, within the FCS is the Flight Guidance System (FGS) that generates roll and pitch guidance commands. Similarly, within the FMS is the Vertical Navigation (VNAV) function that acts like a third crew member in the cockpit, ordering mode change requests and resetting target altitude values to enable the aircraft to track the vertical flight plan.

We have developed formal, executable models of the requirements for the mode logic of a FGS and for portions of the VNAV functionality. We have also conducted a comprehensive software safety analysis on the FGS mode logic model and are completing the analysis of the VNAV model. This analysis uses as its starting point several "traditional" safety analysis techniques such as a Functional Hazard Assessment (FHA), a Fault Tree Analysis (FTA), and a Failure Mode Effects Analysis (FMEA). However, we are also using formal methods techniques known as model checking and theorem proving to verify the presence of safety properties in the model.

This paper summarizes the (now completed) safety analysis that was performed on the FGS model, and highlights the similarities and differences with the (still on-going) safety analysis of the FMS model. In particular, we summarize progress made to date in the use of formal methods to verify the presence of the required safety properties in the models themselves.

Low-Cost Ground-to-Ground Mobile Telemetry Link

A frequency modulated UHF telemetry link giving 5 MHz of bandwidth capacity with carrier to noise ratio exceeding 30 dB is described. The system is intended for ground mobile use and provides more than 1 km of coverage also in moderately obstructed terrain indicating allowable maximum path loss up to 110 dB. The mobile transmitter end uses a sturdy flexible antenna. Typical sensor signals include voltage outputs from accelerometers, strain gauges, and thermistors, but live broadcasting-quality television is also easy to implement. Digital interfacing is accomplished through suitable D/A converters, multiplexers, and coders. Both the transmitter and receiver utilize commercial-off-the-shelf building blocks in order to keep the total cost within acceptable limits.

Wavelet De-Noise for IMU Alignment

Inertial navigation system (INS) is presently used in several applications related to aerospace systems and land vehicle navigation. An INS determines the position, velocity, and attitude of a moving platform by processing the accelerations and angular velocity measurements of an inertial measurement unit (IMU). Accurate estimation of the initial attitude angles of an IMU is essential to ensure precise determination of the position and attitude of the moving platform. These initial attitude angles are usually estimated using alignment techniques. Due to the relatively low signal-to-noise ratio of the sensor measurement (especially for the gyrosopes), the initial attitude angles may not be computed accurately enough. In addition, the estimated initial attitude angles may have relatively large uncertainties that may affect the accuracy of other navigation parameters. This article suggests processing the gyro and accelerometer measurements with multiple levels of wavelet decomposition to remove the high frequency noise components. The proposed wavelet de-noising method was applied on a navigational grade inertial measurement unit (LTN90-100). The results showed that accurate alignment procedure and fast convergence of the estimation algorithms, in addition to reducing the estimation covariance of the three attitude angles, could be obtained.
Buried Small Objects Detected by UWB GPR

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&
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ABSTRACT

A ground penetrating radar (GPR) using short-pulse is developed to detect small and shallow metal objects buried underground. A bistatic mode in which the GPR system uses separate transmitting and receiving antennas is applied. A modified fat dipole antenna is developed for the transmitting and receiving antennas. The prototype of the system is tested in the real environment and 2D visualization of raw data is achieved. We show that the developed system has a good ability to detect underground metal objects, and even small targets of several centimeters.

INTRODUCTION

Recently, impulse radio technology, also called ultra wideband (UWB) technology is receiving much attention for applications to wireless communication and high resolution radar. Its main principle is to use impulses which result in very accurate timing information and ultra wide bandwidth in frequency domain. These features are so useful for the UWB technology to be widely applicable for the detection of unknown or known small and shallow objects buried underground [1-4]. Until now, UWB ground penetrating radar (GPR) systems have been intensively investigated for mine detection [5].

This paper reports a new application of UWB radar for the detection of buried gas pipelines. The UWB GPR is used to draw a map of buried gas pipelines by connecting a global positioning system (GPS) to the GPR. Compared to conventional radar systems, such as FMCW radar, the complexity of the system is reduced, but its performance is better.

In the following sections, we describe the design procedure of the UWB GPR systems. Also, the image processing procedure of the raw data for 2D visualization is shown. Additionally, a novel UWB fat dipole antenna is designed and presented for this system.

UWB GPR SYSTEM CONFIGURATION

In Figure 1, the detection scheme of the entire UWB GPR radar is shown. The radar system is composed of roughly three main parts: a transmitter unit with a portable impulse generator and a UWB transmitting (Tx) antenna; a receiver unit with a UWB receiving (Rx) antenna and a high speed sampling digitizer; and a data processing unit for 2D visualization.

For the system, a bistatic mode is applied. That is, Tx and Rx antennas are separate. The gap between the Tx antenna and the Rx antenna will be kept constant. In moving the transmitter at a foot’s pace, the receiver saves the signal scattered by underground objects. As shown, the system is simple.

Determination of System Specifications

Usually, the gas pipelines are buried within 3 m and made of metal. Thus, for the system, the maximum target depth of 3 m is decided upon and then the operating frequency is chosen to be between 100 and 400 MHz on a 3 dB line. It is true that with higher operating frequencies, the UWB GPR has better localization and identification of targets [3]. However, as explained in [6], the limitation of the operating frequency is determined to be about 400 MHz since the ground in our country usually contains more moisture, thus the attenuation factor is more severe.

Now, for the above desired frequency bandwidth, an impulse generator is developed. Figure 2 displays the impulse shape; it has about 2.5 ns pulse duration. For the impulse measurement, a digital oscilloscope with 5 GS/s is used.

As is well known, a UWB antenna is considered a band pass filter in a UWB system [1, 2]. In other words, a derivative form of the original impulse shape is radiated. In Figure 3, the power spectral density of the derivative of the pulse shape in Figure 2 is shown. The figure shows that the frequency bandwidth is between 150 and 500 MHz on a 3 dB line (fractional bandwidth is more than 150% on a 10 dB line).
antenna for better excitation. The gap of two arms is selected to be 0.1 times as long as that of each arm. Mainly, with an aid of simulation, proper dimensions of an antenna are determined for the desired frequency bandwidth. In this paper, by considering the impulse generator, the arm dimension is chosen to be 240 mm × 500 mm. The attractive advantages of the antenna are easy fabrication, low cost, and light.

Figure 5 shows the VSWR measurement of the designed antenna.

![Frequency Response](image)

**Fig. 3. Power spectral density of the derivative form of the impulse**

<table>
<thead>
<tr>
<th>frequency (MHz)</th>
<th>power spectral density (dB)</th>
</tr>
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<tbody>
<tr>
<td>100</td>
<td>-25</td>
</tr>
<tr>
<td>200</td>
<td>-20</td>
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<td>300</td>
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<td>-5</td>
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<tr>
<td>600</td>
<td>0</td>
</tr>
<tr>
<td>700</td>
<td>5</td>
</tr>
</tbody>
</table>

**Fig. 4. Modified fat dipole antenna. Substrate material is FR 4 (εₘ = 4.8)**

![Antenna Image](image)

**Transmitting and Receiving Antennas**

It is important to design a proper UWB antenna in order to transmit impulses into the ground and receive scattered signals from objects with minimum distortion. In this paper, a modified fat dipole antenna with a broad bandwidth, between 100 and 350 MHz is developed.

Figure 4 shows the planar fat dipole antenna. The substrate of FR 4 (εₘ = 4.8) is used. To transmit more power into the ground and prevent the received signals from the external undesired signals, a parabolic reflector is used for each antenna. Also, as shown in the photograph, the edges of the antenna are connected to the 100 Ω resistor in order to prevent the ringing effects from the original scattering signals by objects. A BNC connector and 50 Ω coaxial cable are used for the Tx and Rx antennas. The PVC coat of the coaxial cable is removed and the outer shield is welded to one arm of the

**Data Processing Algorithm**

As mentioned previously, a high speed digitizer is used for measuring the backscattered signal in the receiver unit. In this paper, the digitizer has 5 GS/s sampling rate, an internal delay line, a 14 bit resolution, and the ability to average up to 10,000 times, to obtain a higher dynamic range. The receiver unit is
designed to gather backscattered signal in memory via a GPIB cable.

For visualization, digital signal processing of the raw data is necessary. A commercial delphi program for 2D visualization is used. Figure 6 shows the 2D GPR image signal processing algorithm for the system. As shown in Figure 6, the procedure of 2D visualization is as follows: The envelope detection on each A-scan is fulfilled by finding absolute values of the Hilbert transform, and then the A-scan results are arranged in adequate B-scan. For a good A-scan, A-scan data at a point are obtained by averaging several tens of A-scan results. For a B-scan, some image preprocessing tools such as filtering, smoothing, and varying threshold, and removing background noise are applied. The program for visualization makes it possible to distinguish other buried objects by assigning a color depth table obtained through B-scan data processing. The results are displayed in next section. The algorithm is explained in detail in [7].

MEASUREMENT AND RESULTS

The whole system is set up and tested in a real environment. Figure 7 shows an outside test-bed built near the Institute. In the ground, a metal plate is buried at a depth of 100 cm, a metal pipe of 40 cm diameter at 100 cm, a metal pipe of 5 cm diameter at 50 cm, and a PVC pipe of 20 cm diameter at 50 cm. The distance of 200 cm between two targets is fixed. Metal pipes of two different sizes are buried for testing the performance of the UWB GPR. The total length of the test bed is 10 m. It should be pointed out that, in addition to the buried targets, lots of small or large stones and plant roots exist in the test field.

Impulses are transmitted into the ground at every 5 cm and reflected impulses are recorded in memory. In Table 1, the parameters used in measurement are summarized.

Figure 8 shows images of raw data. Figure 8A shows the image before the removal of the background image. Figure 8B is the image with a lower threshold value than that in Figure 8A. The black and white lines in the middle are from the strong direct wave and the surface reflection. The black and white lines at the bottom show the reflection at the maximum depth. Figure 8C illustrates an image after removing the background image. As shown in the figure, three different metal objects are clearly distinguishable. However, the PVC pipe's image is not clear. Also, several small scatters are found. By comparing the transmitting and receiving signals, the maximum depth of 3 m is derived.

According to the resolution, the depth resolution in the vertical plane and the space resolution between two objects can be considered. The depth resolution of about tens of centimeters is observed. The reason for lower depth resolution is that the lower frequency range is used. In other words, to improve the depth resolution, the frequency bandwidth of the impulse signal becomes broader at the cost of the reduction of maximum depth. One of the solutions will be the better A/D (analog to digital) converter with higher sampling speed. Also, the space resolution appears unsatisfactory. We assume that the reason for the space resolution problem is due to less B-Scan numbers.

However, measurements show that the developed radar has a good ability to detect buried metal objects, even small targets of several centimeters.
CONCLUSION AND FURTHER WORKS

A UWB GPR radar is developed to detect underground metal objects. The design procedure of the system is explained. Measurement results show that the UWB GPR has good ability to find underground metal targets. For further works, the performances will be tested and compared to conventional radars. Also, steps for improving resolutions will be taken.

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Ultra-Wideband, Short-Pulse Electromagnetics,
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Proc. of the IEEE Summer Annual Conf 2002,

Fig. 7. Test bed in real environment for testing the performance of the developed UWB GPR.
A thin metal plate, two metal pipes, and a PVC pipe are buried. D stands for diameter

Table 1. Summary of parameters in measurement

<table>
<thead>
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<td>Pulse Repetition Frequency (PRF)</td>
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<td>Station Spacing</td>
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<tr>
<td>Sampling Interval</td>
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</tr>
<tr>
<td>Number of B-scans</td>
<td>158 points</td>
</tr>
<tr>
<td>Samples per A-scan</td>
<td>500 points</td>
</tr>
<tr>
<td>Separation of Tx and Rx antenna</td>
<td>0.8 m</td>
</tr>
<tr>
<td>Frequency Bandwidth</td>
<td>100-300 MHz</td>
</tr>
</tbody>
</table>

Fig. 8A. Image with background image  Fig. 8B. Image with lower threshold value

Fig. 8C. Image after removing the background image

Fig. 8. Images in processing raw data

A study on the image techniques for UWB-GPR system,
accepted for the publication in Proc. of Asia Pacific Microwave Conference 2003 (APMC '03).
Commercial Technology & Avionics Architecture

Chris Wilkinson  
*University of Maryland*

**ABSTRACT**

As commercial technology has become more embedded in the military community, there have been attendant effects caused by the rapid progress in technology and by obsolescence. Industry has generated many solutions to mitigate these effects, but their limitations are emerging with time. This is a discussion of higher-level approaches to obsolescence solutions and technology insertion problems that have not hitherto been addressed.

**INTRODUCTION**

Over the last few years, there has been an increasing shift by avionics manufacturers away from military specified parts to commercial parts as the supply of military rated parts has dried up. This has been driven by the combined effects of reduced military spending, a withdrawal from the market by parts suppliers of military parts, a drive for lower cost avionics, rapid progress in semiconductor technology, and a desire to access this leading edge technology by the avionics suppliers in order to offer cost-effective solutions to their customers [1].

The shift to commercial parts and technology has brought with it some well-known disadvantages; such as obsolescence referred to by the military community as Diminishing Manufacturing Sources and Material Shortages (DMSMS), and reduced environmental capability. These are severe problems for avionics manufacturers, air vehicle manufacturers, and end-users alike, not the least of which is the time and expense of recertification of a product after a change has been made to recover from an obsolescence problem. Certification authorities are understandably nervous about the consequential effects of seemingly minor changes, and thus require considerable verification activity to be documented.

The military and commercial aerospace industries have generated many targeted solutions to mitigate these effects [2, 3]. These are working to some extent but some limitations to their efficacy are emerging. It is not the intent to revisit those solutions or discuss their merits and limitations, but to discuss some higher-level architectural and business oriented approaches to obsolescence solutions and new technology insertion problems that have not hitherto been addressed.

**AVIONICS ARCHITECTURE**

Avionics architectures are, in general, the purview of the airframe manufacturers who are responsible for the first level of requirements analysis and functional breakdown. This leads to an aircraft architecture and sub-system requirements that become procurement specifications against which avionics suppliers bid. The downsizing of tier 1 aircraft manufacturers leads them to define larger and larger sub-systems as procurement items, letting the tier 2 sub-system supplier perform a larger share of the integration process [4]. Increasingly the successful player is the one who can demonstrate a systems integration capability and manage a multitude of third tier suppliers. The supply chain will become the supply “web” already seen in other industries, as separate
suppliers of sensors/actuators, aircraft wiring, cabinets, modules, and application software emerge. The contractual difficulties of managing a large number of suppliers must not be underestimated.

Avionics suppliers have, in the past, responded with so-called “federated” architecture solutions where the sub-system requirements are further decomposed into functional requirements that are implemented by a number of LRUs as in Figure 1. Since typically, each major function is allocated to an LRU (or group of LRUs), this has led to there being a large number of dissimilar LRUs on the aircraft, each with its own unique supports requirements, i.e., spares holdings, test equipment, technical publications, etc.

This approach has been feasible and cost-effective in the past, since it was possible to obtain parts that had an environmental capability, suitable for the harsh environment in which they are used. Increasingly this is no longer the case as the environmental capability of parts reduces to the typical office environment. It is no longer feasible to consider placing significantly complex avionics in such severe environment locations as wings, wheel bays, and engines.

The environment within the equipment bays of an aircraft is substantially more benign and can be controlled to a much greater extent than in remote locations. There is, therefore, a technology push toward a centralized architecture that puts most of the computation and processing within an environmentally-controlled area, whilst leaving simplified (i.e., dumb) sensors and actuators at the point of action. By simplifying the remote electronics to the maximum extent, it becomes possible to design both the local environmental conditioning and the remote electronics environmental capability. It is not reasonable to hope that local environmental conditioning can be applied to complex, high-power dissipation computing intensive functions in the outer reaches of the airframe, or that the capabilities of an ECS can be extended out to these remote parts of the aircraft. Thus, in this centralized model, we may consider the problem in three parts:

- The centralized computing
- The sensor and actuators
- The means by which they interconnect.

CENTRALIZED COMPUTING

The safety requirements for an aircraft almost mandate that redundancy be applied, since the reliability offered by single-lane systems cannot approach the $10^8$ requirement for safety critical systems. Redundancy has been most often provided by physically separate computing elements to minimize the probability of common mode failures. Thus, centralization does not mean “all in one box” but rather means two (or more) physically separated locations within the environmentally controlled area of the airframe. So conceptually, at least, we may imagine two or more redundant computing “hubs” as in Figure 2.

At a most basic level, any avionics function can be reduced to input, output, and processing. If we consider that sensors/actuators take care of the interface with the physical world, the input and output may become standardized and applicable across a wide variety of functions. Similarly, computing is common across many functions. This is the idea underlying the concept of “modular” avionics (IMA). A centralized architecture, insulated from the outside world by sensors and actuators, can capitalize upon standardization to reduce the plethora of unique LRUs to a more manageable set of modules. The modules themselves should be designed so far as is possible so there is a maximum of commonality, even if this means that certain functions are provided with more power than is strictly necessary. The supportability benefits of commonality will outstrip, by far, the costs of over-provisioning of computing. The standardization brings advantages in obsolescence management (modules can be upgraded), scalability (same), logistics footprint (fewer unique part numbers).

It should be noted that modularity and integration are distinct concepts that are not necessarily connected. Integration can be accomplished in a federated architecture, though it may not be very cost-effective to do so. With integration and modularity, it becomes possible to consider decoupling the hardware from the function so that dynamic reconfiguration of functions across hardware modules is
feasible. There are obvious benefits to be had such as deferred maintenance.

The interconnect of modules is a critical factor, since this is an item which will be built into the structure of a rack and is, thus, inherently difficult to upgrade and will in any case need backward compatibility with existing modules. There is a need for a backplane bus which can offer the integrity, segregation, and speed required. There is a very great challenge to make this scalable and "future-proof" in order that upgrades to modules will not be hobbled by a creaking support structure. At present, there does not appear to be any databus design in use or on the horizon that meets these needs.

As the performance capability of semiconductors increases, so does the power consumption. The NEMI and SIA roadmaps provide forecasts for those [5,6]. The thermal problem is already being felt in conventional LRU's and will increase as more functionality is packed into ever smaller spaces. The modular approach provides an opportunity (and a need) to develop some novel thermal solutions that are not practical in a conventional LRU. Thermal bussing from component, through card, backplane, rack, ECS, and through to the final heatsink (outside air) provides an opportunity to lower the total thermal path resistance by at least one order of magnitude. There are many novel thermal management solutions available, but the product engineering is lacking.

**SENSORS AND ACTUATORS**

The simplicity of parts needed to implement these and the usually low power needs, makes it feasible to apply the well-known techniques of uprating, ASICS, and other custom designs. Most often, the packaging of these devices is very airframe-specific, entailing unique mounting requirements. In general, these would best be maintained by return-to-supplier who would be free to make whatever internal part or sub-assembly substitutions were necessary to restore the part to working order according to its requirements specification. The regulatory impact of such substitutions should be negligible.

**AIRCRAFT BUSES**

This model depends largely on the cost-effectiveness of interconnect between sensors/actuators and centralized computing. There are many candidates for such buses, but the ones now typically employed in aircraft, such as MIL-STD-1553 or ARINC-629, carry such a large price tag (~$1000) that it is economically impractical to consider these as usable in large numbers. Furthermore, the data rate offered by these is woefully low compared to the needs of new aircraft functions. In contrast, we may look at 10BASE-T used for office Ethernet connections to find a cost/node in the region of $20 at 100Mbits/sec. Thus, there is a need to find a low-cost aircraft bus solution that can meet avionics requirements for integrity, determinism, segregation, EMC, and throughput. There are many commercial candidates that could easily be adapted to the specific requirements of avionics.

ARINC-664/AFDX is one such bus actively under development.

**SUPPORTABILITY**

The market lifetime of a commercial part is very often not required to be greater than 3-5 years, since the products in which they are mainly used have a similarly limited market life. In addition, these product sectors are extremely cost-sensitive and therefore the pressure to shave part cost is relentless. This may lead to part design margins being eroded to the extent that the essentially unlimited part life we have until now assumed, cannot be assumed any longer. This possibility raises a number of concerns, for example, the validity of MTBF-based safety predictions and the certification basis and also the prospect of requiring scheduled maintenance based on operating hours or some life-consumption prognostic measure such as one derived from a recorded environmental exposure time history and life consumption calculation using life models or "canary"-type monitors.

Deferred maintenance becomes feasible in a modular architecture since the flexibility to load-share tasks among computing elements would enable faults to be absorbed and prognostics would permit a reduction of unscheduled maintenance actions. Both of these allow a concentration and deskilling of maintenance facilities with consequent benefits to the flexibility of route structure or mission deployment scenarios.

Some aspects of supportability have been alluded to above. A modular architecture makes possible some support scenarios that have not been attainable. Obsolescence is not a problem that is going away. The question is: What is the least expensive way to manage it? The central proposition in an architectural approach to obsolescence is that it can only be cost-effectively managed at the sub-assembly level and that conventional obsolescence prediction methodologies are, at best, only firefighting. Third-line, end user operated support operations are destined to be replaced with throwaway modules and OEM-contracted repairs or replacement. "Power-by-the-hour" is a business model well accepted in the engines business and this is a concept that could well be extended to the avionics arena.

**SYSTEM CERTIFICATION**

It must be remembered that there are certain barriers to implementation of a modular architecture which may be classified as regulatory and commercial. To realize the benefits of modularity, it becomes necessary to consider how to certificate a system that will be undergoing almost continual upgrade throughout its service life. The present regime of initial certification followed by recertification following even small changes will not be affordable to the industry or the paying passenger. The regulatory barrier is not insurmountable, but will require a cross-industry and governmental effort to establish relevant regulations and
design guidance documents. This, in turn, will require design approaches and management practices that can prove (or at least demonstrate) and document robust spatial and temporal partitioning of multiple dissimilar functions co-located within a single piece of hardware so that additional or improved functions can be inserted incrementally and existing functions can be supported without a major recertification effort being mounted [7].

CONCLUSIONS

Supportability issues are increasingly coming to dominate the life cycle cost of avionics. The old approaches of managing obsolescence at the component level through numerous databases and point solutions are too expensive and slow to respond effectively to the rapid rate of obsolescence being experienced.

The longer term solution lies in the design of avionics from an architectural level down so that obsolescence problems and functional upgrades are managed by continuous upgrade of a minimal set of common modules that can be changed internally whilst providing a consistent user interface and whose configuration is under the control of the OEM. This approach controls otherwise massive recertification costs.

The current multi-level support scenarios require a more distributed infrastructure. The concomitant logistics cost could be reduced substantially to a more centralized and lower cost model by the adoption of modular design.

To achieve these ends requires: firstly, a recognition of the true costs of support; and secondly, industry and regulators to jointly address the problems of assuring safety of flight in a continuous upgrade scenario and put in place a set of design guidelines and certification practices.

Lastly, in conclusion it should be pointed out that the trends in electronic components are not all bad as might be inferred from the foregoing. As well as the obsolescence and decreasing environmental capability limitations, functionality and integration density, both at the die and package level, continues to advance at a brisk pace. There are thus emerging, new possibilities for avionics design that were technically or economically infeasible just a few years ago. These new opportunities should be embraced.

ACKNOWLEDGEMENTS

The author is grateful for the improvements to the original draft suggested by Lloyd Condra at Boeing.

ACRONYMS

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<th>Description</th>
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<tr>
<td>MTBF</td>
<td>Mean Time Between Failure</td>
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<td>EMC</td>
<td>Electromagnetic Compatibility</td>
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<tr>
<td>ARINC</td>
<td>Aeronautical Radio, Inc.</td>
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<td>ASIC</td>
<td>Application Specific Integrated Circuit</td>
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Wireless Interconnection to Test Instruments

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ABSTRACT

Manufacturers are increasingly offering Ethernet connectivity on their test instruments. An additional benefit of this connection method is the ease of conversion to wireless connectivity. This paper describes the Ethernet interface used in the remote control of a RF power amplifier and describes the conversion to wireless connection.

INTRODUCTION

The use of Ethernet connection using Transmission Control protocol / Internet Protocol (TCP/IP) has exploded due to the growth of the Internet. The same technology has been used to create Local Area Networks (LANs) with the result that Ethernet LAN cards are readily available and inexpensive. Manufacturers are increasingly offering Ethernet connectivity as a means of monitoring and controlling their test instruments via a LAN. A PC equipped with an Ethernet interface card and running a regular web browser are all that are needed to communicate with these test instruments. Add Internet access to the LAN and the test instrument can be operated from anywhere in the world.

When it suits the application, the twisted pair connection to the test instrument can be replaced by a wireless link. Consumer electronics used in WiFi for the home provide the components for the wireless link that comprises a wireless access point at the test instrument and a wireless network card in the PC. The operation of the remote control interface remains the same as when using the twisted pair connection.

RF POWER AMPLIFIER ETHERNET INTERFACE DESCRIPTION

The card inside the RF Power amplifier incorporates a special purpose Web page server providing the amplifier's status via a "form" written in Hyper Text Markup Language (HTML).

The card also supports Dynamic Host Configuration Protocol (DHCP) to allow seamless connection with existing

Fig. 1. Screen-shot of the form permitting control and monitoring of the RF power amplifier via the Ethernet interface.

networks. If required, the IP address of the card may be set via a separate port on the card. The form is shown in Figure 1. Data to set the amplifier parameters are input by clicking the relevant text entry box and entering data via the PC keyboard.

Radio buttons are used to change the status of the amplifier and to submit data that has been entered into text boxes. The read back data on the screen is refreshed at regular periods determined by the user.

Radio buttons / Data Input boxes on the form permit:
The target market for WiFi wireless links is businesses and homes. The links currently operate in the unlicensed 2.4 GHz and 5 GHz frequency bands. The 2.4 GHz band (802.11b) offers a data rate of 11 mega bits per second (Mbps), utilizes Direct Sequence Spread Spectrum (DSSS), and has a range of about 300 feet. The 5 GHz band (802.11a) offers a data rate of 54 Mbps, utilizes Frequency Hopping Spread Spectrum (FHSS), and has a range of about 150 feet.

A wireless access point with an integral router is shown connected to the RF power amplifier in Figure 2. The particular wireless access point uses the 2.4 GHz (actually 2.4 GHz to 2.4835 GHz) band and comes complete with a 4-way port switch. A regular twisted pair cable (category-5 10BaseT) connects one of the 4-switched port outlets to the Ethernet RJ-45 connector on the rear panel of the RF power amplifier. The other 3 ports may be connected to other test instruments as required.

A PC or laptop fitted with a wireless network adapter card is used to communicate with the amplifier over the wireless link. The remote operation of the amplifier is identical to that described for the wired Ethernet connection in the section entitled: RF Power Amplifier Ethernet Interface Description.

There is the issue of the RF power amplifier emitting strong signals at 2.4 GHz that could swamp the signal in the wireless link. This would be the case in a power amplifier with a frequency range of, say 0.8 to 2.5 GHz. When the amplifier is emitting at 2.4 GHz, will the wireless link be disabled? This should not happen due to the inherent noise immunity of the spread spectrum approach, but jamming of the signal caused by saturation of the signal receiver circuits is a definite possibility. One solution could be to use a wireless link at 5 GHz (802.11a).

SECURITY

A serious issue with wireless connectivity is security. As long as they are in range, there is nothing to prevent unauthorized access to the wireless network via a laptop equipped with a wireless network adapter card. This is a widely shared concern, especially among businesses, and a concerted effort is underway to prevent unauthorized access. An alliance of suppliers to this nascent market has been formed and the availability of links with access control and data encryption is only a matter of time.

CONCLUSION

Needs work. There are security issues with this connection method being addressed by the suppliers to the WiFi market, but the low cost of these electronic consumer items and the ease of implementation make wireless connectivity worthy of consideration.

Fig. 2. Wireless Access Point connected to the RF Power Amplifier

- Control of the amplifier output mode (Amplifier ON or in STANDBY)
- Control of the amplifier output power level
- Control of the reflected power threshold alarm
- Monitoring of the forward RF power value
- Monitoring of the reflected RF power value
- Monitoring of the amplifier fault status.

The form shown is used when the amplifier is in automatic level control (ALC) mode. Another form can be selected that has the parameters / controls associated with fixed gain control of the amplifier.

CONVERSION TO WIRELESS CONNECTIVITY

Wireless connectivity can be useful where running cables is difficult, unsightly, or dangerous, or where the traditional ATE vertical rack arrangement with wire interconnections is too constricting. In the case of a RF power amplifier, mounting the amplifier within the traditional ATE rack can mean excessively long RF cables to the unit under test, resulting in unnecessary power loss. Also, RF power amplifiers generate significant amounts of waste heat. Wireless connectivity means the amplifier can be positioned away from the ATE rack, if necessary in another room, without the need to run cables.
Automotive-Grade MEMS Sensors Used for General Aviation

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Athena Technologies, Inc.

ABSTRACT

The Attitude Heading Reference System (AHRS) provides data for primary flight instruments, head-up displays, autopilots, and moving map navigation systems. Advances in solid-state MEMS rate sensors, coupled with Kalman Filter algorithms designed to mitigate high drift rates, provide the basis for low-cost, high-performance AHRS for general aviation.

This paper describes the performance of a low cost, miniaturized AHRS using automotive-grade MEMS sensors. The performance of the system is detailed. The implications for certification of this class of system and fault tolerance are discussed.

INTRODUCTION

Growth in General Aviation is predicated on precision navigation, flight path coordination, and near all-weather operations [5]. One of the key enabling technologies is the availability of low-cost, high reliability, accurate navigation sensors to provide data for display on a Primary Flight Display (PFD), transmission for Aircraft Dependent Surveillance (ADS-B), and flight guidance and control for Highway-in-the-Sky (HITS). This data includes pitch/roll/heading attitudes, position, velocities, and accelerations.

In General Aviation, attitude data is generated from mechanical vertical gyroscopes (bank and pitch), and a directional gyroscope/compass/flux valve (direction). These electro-mechanical systems, introduced first in the 1950s, require frequent maintenance (e.g., every 700 hours) and exhibit limitations on accuracy.

Ring laser gyro-based navigation systems, without spinning wheels or gimbals, or dependency on vacuum tubes, significantly improve accuracy and reliability. These systems, at cost in excess $100 K, are prohibitive for General Aviation aircraft.

Breakthroughs in silicon fabrication technology, coupled with widespread application in automotive applications (e.g., airbags), have created availability of very low-cost MEMS inertial sensors for General Aviation navigation sensors. Modern General Aviation navigation systems, based on these MEMS inertial sensors, include AHRS, such as Crossbow’s AHRS500GA [10], integrated INS/GPS, such as Systron Donner’s CMIGITS [2], and integrated INS/GPS/Air Data, such as Seagull’s ADAHRS [8].

This paper describes the performance of a low-cost, miniaturized AHRS using low-cost automotive-grade MEMS sensors, digital magnetometer, and GPS. A Kalman Filter algorithm is used to blend data to maximize the long-term accuracy of the GPS and magnetometer, with the short-term accuracy of the inertial sensors. This product, known as the SensorPac, was developed by Athena Technologies, Inc.

The next section provides a technical overview of the system. The following sections describe the methods used for testing and the results of these tests. The conclusion discusses implications of these results and future work.

LOW COST AHRS DESCRIPTION

The widespread use of MEMS angular rate gyro in automotive airbags among other applications, has created economies of scale that have driven the price of these sensors to order of magnitude of $50 a sensor [3].

Low-cost AHRS are achievable using these solid-state MEMS sensors as “strapdown” inertial measuring devices. Instead of measuring the angular motion of the aircraft around a gimbaled spinning mass gyro, the outputs of solid-state angular rate gyro are mathematically integrated over time to compute the angular motion.

These low-cost MEMS angular rate sensors, however, exhibit low accuracy and noisy outputs that result in excessive drift rates. For example, high precision spinning mass gyro can provide drift rates of less than 0.0001 degrees/hour [4]. A low-cost MEMS gyro, initialized in a static level orientation, will drift on the order of 6 degrees/minute. With this level of drift, attitudes would exhibit errors of 90 degrees in 15 minutes.
The basic method for correcting these drift rates is to use a vertical and heading reference to establish a local level from which aircraft body angles can be measured. There are two schemes that are applied:

- **Pendulum Accelerometers**
  This technique uses the Earth’s gravitational vector and magnetic heading as a reference. Accelerometers, acting as pendulums, sense the direction of the accelerations due to motion of the vehicle with respect to the acceleration of the gravitational field. A Kalman Filter adjusts biases to compensate for the errors between the attitudes integrated from the angular rate gyro, and the attitudes of the vertical reference and the magnetic heading. Several additional compensations are required to null the effects of centrifugal/centripetal accelerations during long duration turns and high-g dynamic maneuvers. An example of an AHRS that uses this method is the Crossbow AHRS500GA [10].

- **GPS Velocities**
  An alternative method for establishing the vertical and heading reference is through the use of an external source for the velocities, such as a GPS, and a magnetometer. Implementations which rely on a GPS must be designed to handle GPS outage through reversionary modes. An example of an AHRS that uses this method is Systron-Donner’s C-MIGITS [2].

An alternative approach to improving attitude from MEMS inertial sensors is through the use of multiple GPS antennas [1].

**Low-Cost AHRS Description**

The navigation system used in this study, illustrated in Figure 1, includes 3-axis accelerometers, 3-axis rate sensors, 3-axis magnetometer, and a 12-channel GPS. A Kalman Filter blends data from these sensors to maximize the accuracy of the navigation data.

The Kalman Filter is a variable dimension model structured to estimate states by propagating errors over time. A typical dynamic error model that can be used for the error propagation in the analysis of AHRS consists of the following states:

- Velocity errors (3x)
- Angular (attitude) errors (3x)
- Gyroscope bias errors (3x)
- Accelerometer errors (3x)
- Wind error corrections (2x)

**Fig. 1. Low-Cost AHRS Configuration**

**Fig. 2. Variation in attitude computations for a static low-cost AHRS**

- Magnetic heading reference error
- Airspeed sensor bias error

Typical AHRS performance characteristics achieved by state-of-the-art (non-MEMS) inertial sensors [7]:

- Heading attitude (RMS) 0.5 deg (true) 0.8 deg (mag)
- Pitch attitude (RMS) 0.2 deg
- Roll attitude (RMS) 0.2 deg
- Angular rates (RMS) 0.1 deg/see
- Ground speed 4 knots
- Linear Acceleration 0.1 m/s²
Fig. 3. 3-Axis Attitude Rates of Change and 3-Axis Accelerations Derived from Kalman Filter Exhibit Stability during Static Tests

The navigation data is transmitted via RS232 at a variety of programmable rates up to 100Hz. In addition to the attitude position, and velocity data, the inertial instrument biases, scale factors, and GPS time are also transmitted. This low-cost AHRS unit is housed in a 2" x 3" x 4" casing. The unit draws less than 5 W power and exhibits a calculated MTBF of greater than 20,000 hours. A production run of greater than 100 units will yield an AHRS for less than $10,000.

LOW-COST AHRS PERFORMANCE

The accuracy of low-cost AHRS was evaluated in static lab tests and flight tests.

Static Test Performance

The static performance of the low-cost AHRS was measured with the unit at rest on a laboratory bench. The unit was connected to an external GPS antenna. The unit was powered up and allowed to process through the alignment phase in which the Kalman Filter solution converges. Data was gathered for 4 minutes (Figure 2).

For the duration of the test, the unit provided constant pitch, roll, and yaw data as follows:

- Pitch (Theta) RMS = 0.0254 deg for 220 secs
- Roll (Phi) RMS = 0.03521 deg for 220 secs
- Yaw (Psi) RMS = 0.02422 deg for 220 secs

Fig. 4. Roll attitude vs. roll reference from inflight data

This stability is reflected in the attitude rate-of-change and acceleration states derived from the Kalman Filter (Figure 3).

Flight Test Performance

Flight testing of the low-cost AHRS has been conducted. A sample of error data for maneuvers between 5,000 and 10,000 feet:

- Pitch Attitude (RMS) = 0.023 deg
- Roll Attitude (RMS) = 0.0499 deg

These values are derived by comparing Pitch and Roll from the Kalman Filter solution with estimates of Pitch and Roll that satisfy the Gimbal Equations [6], combined with kinematics of low rate-of-climb/descent flight.
• \( \Phi - \text{dot} = p + q \sin(\Phi) \tan(\Theta) + r \cos(\Phi) \tan(\Theta) \)

• \( \Theta - \text{dot} = q \cos(\Phi) - r \sin(\Phi) \)

• \( \Psi - \text{dot} = q \sin(\Phi) \sec(\Theta) + r \cos(\Phi) \)

Figure 4 illustrates the roll attitude and the reference roll attitude from 8 minutes of flight data.

Figure 5 shows the relationship between raw GPS velocity (N/S and E/W in m/s) and Kalman Filter velocity (N/S and E/W in m/s). Kalman Filter velocities, biased by short-term accuracies from inertial sensors, provide accurate, smooth velocity data.

CONCLUSIONS

The low-cost AHRS described in this paper defines a mature and viable navigation system for General Aviation aircraft. The low-cost AHRS provides accuracy with performance better than minimum TSO performance standards.

The ease of production and the versatility of the low-cost AHRS make this system a building block for precision navigation systems envisaged for the future of General Aviation.

Fault Tolerance

Traditional AHRS achieve reliability through redundancy. For example, dual AHRS are used to cross-check each other's data, or triple AHRS are used in an averaging scheme.

An alternative approach to fault tolerance, demonstrated by Vos [9], takes advantage of the fact that an integrated sensor suite provides an over-determined state-space. Data from one set of sensors is processed by equations of motion to compute an estimate of data from another sensor. In this way the estimated data is compared to the measured sensor data to determine integrity.

This technique provides the mechanism to improve the integrity of the data, without adding to the cost and complexity of redundant systems.

Certification

Certification of this class of navigation system has been demonstrated [10]. The low-cost AHRS described in this paper is designed to satisfy certification regulations. The software was developed to meet the DO-178B Software Considerations in Airborne Equipment Certification. The hardware was designed to meet the environmental requirements for altitude, temperature, shock, and vibration as specified in DO-160D Environmental Conditions and Test Procedures for Airborne Equipment. Finally, the product will be certified and manufactured to meet the minimum performance standards defined by TSO-C4e for Bank and Pitch Instruments, TSO-C3d for Turn and Slip Instruments, and C6d for Gyroscopically Stabilized Magnetic Direction Instruments.

With sufficient resources and patience, Supplementary Type Certification (STC) will be submitted for Class I-III aircraft.

ACKNOWLEDGEMENTS

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UWB Implications for Spectrum Management

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ABSTRACT

This paper presents some of the challenges facing the introduction of ultra-wideband (UWB) technology in wireless applications intended for commercial use, summarizes relevant regulatory and standards developments, and addresses potential implications on spectrum management and radio regulations.

INTRODUCTION

The radio spectrum is an international limited resource. The use of radio frequencies by wireless services is regulated by the Radiocommunications Sector of the International Telecommunications Union (ITU-R) and by the national spectrum management authorities. To minimize harmful interference, the radio spectrum is traditionally segmented into several frequency bands. The ITU-R usually allocates each band to one or more wireless services either on a worldwide or regional basis. The spectrum management authorities in each country set standards for wireless devices and allocate frequency bands to wireless services based on national needs and, mostly, in harmony with the ITU-R allocations and regulations.

Wireless services can share frequency bands on a primary and secondary basis. Primary services can claim protection from harmful interference. Secondary services shall not cause harmful interference to a primary service, shall not claim protection from harmful interference from primary services, and can claim protection from same or other secondary services to which frequencies may be assigned at a later date.

Wireless devices are usually licensed. However, some low-power devices are licence-exempt and operate on a "no-interference, no-protection" basis. Licence-exempt devices traditionally operate in specific frequency bands and comply with certain emission levels.

UWB systems are intended for operations on a licence-exempt basis in multiple frequency bands allocated to several wireless services. On one hand, this could improve spectrum utilization. On the other hand, there are concerns about the proliferation and the potential aggregate interference from multiple UWB devices. The introduction of UWB in applications intended for commercial use brings additional challenges to the radio regulators and the traditional way of spectrum management as discussed in this paper.

PROPOSED FREQUENCY BANDS FOR UWB APPLICATIONS

In 2002, the Federal Communications Commission (FCC) of the USA authorized the sales and operations of three types of UWB systems on a licence-exempt basis subject to certain restrictions [1]:

1. Communications and measurement systems are authorized in 3.1-10.6 GHz. These systems are intended for short-range communications for indoor use and outdoor hand-held devices for peer-to-peer operations.

2. Vehicular radar systems are authorized in 22-29 GHz with a centre frequency above 24.075 GHz. These systems are intended to detect the movement and location of objects near vehicles and to avoid collisions. In addition, the FCC proposed additional new rules (February 2003) to deal with potential UWB vehicular radar in 3.1 - 10.6 GHz.

3. Radar imaging systems: These systems can be used to obtain images of obstructed objects. They are authorized below 960 MHz and in:
   3.1. - 10.6 GHz: for through-wall image detection systems and surveillance systems; and 1.99-10.6 GHz: for wall imaging, ground penetrating radars (GPR), and medical
imaging systems. For GPR and wall-imaging devices manufactured prior to July 2002, the FCC issued a waiver allowing them to operate in all frequency bands below 10.6 GHz.

In addition, the Fixed Satellite Service (FSS) in Japan intends to use UWB in uplink and/or downlink satellite communications to develop new applications potentially in the Ka and Ku bands [2].

Footnote 5.340 and Article 4.4 of the ITU-R Radio Regulations (RR) [3] have regulatory implications relevant to the introduction of UWB in some of these frequency bands. Footnote 5.340 prohibits all emissions in a number of frequency bands mostly used by passive services (Radioastronomy and Earth exploration satellites). However, Article 4.4 allows administrations to assign frequencies in these bands on a no-interference and no-protection basis.

### SPECTRUM MANAGEMENT CHALLENGES

The introduction of UWB in wireless applications intended for commercial use faces many challenges:

1. Finding a suitable spectrum for UWB applications: UWB emissions spread over very large frequency bandwidth and require a few GHz of spectrum to operate. The FCC adopted a solution that allows low power UWB systems to operate on a licence-exempt basis in frequency bands allocated to other wireless services [1].

2. Licensed or Licence-exempt UWB? Regulators are trying to figure out whether all UWB devices have to be licensed or licence-exempt, and whether some applications may have to be licensed or permitted only to certain user groups. Radar imaging, vehicular radar, and communications and measurement systems have different operational and technical characteristics, market status, potential proliferation, and potential impact on other wireless services [4]. Some of these applications operate infrequently and can co-exist easily with other services. Other UWB applications such as wireless personal area networks (WPANs) operate at a high percentage of time and, thus their potential impact on other services needs to be evaluated.

3. Implications of allowing UWB in specific bands: Opponents of UWB are of the view that UWB cannot be introduced if it produces emissions in frequency bands to which footnote 5.340 of the RR applies. Proponents of UWB are of the view that Article 4.4 of the RR is sufficient justification for UWB to operate across these bands. In addition, there are concerns raised by licensees of spectrum obtained by auctions about allowing UWB in their bands. The issue of spectrum property rights is open for debate.

4. Compatibility with wireless services: The introduction with UWB applications without causing harmful interference to other wireless services is a requirement. Wireless UWB devices are to transmit at a power level less than or equal to the licence-exemption level currently set for conventional wireless devices (-41.3 dBm/MHz). UWB communication systems such as WPANs have the potential of high-density use in specific areas such as office buildings and conference centres. There are concerns about the proliferation of UWB devices, their aggregate impact on spectrum usage (e.g., RF noise floor), and potential harmful interference from multiple UWB devices.

5. Increased demand on spectrum for wireless networking: The ISM band 2.4 GHz is saturated in some urban centres, the band 5.8 GHz is being used increasingly. The FCC recently opened the 24 GHz ISM band for Metropolitan Area Networks (MANs). In addition, the World Radio Conference (WRC-03) recently allocated additional spectrum for wireless access systems including wireless LANs in the 5 GHz band (5 150 - 5 350 MHz and 5 470 - 5 725 MHz) [4]. In comparison to other wireless networking technologies such as Bluetooth and IEEE 802.11 (or WiFi), UWB is advantageous in a

### Table 1 Current intended frequency bands for UWB applications

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<th>FCC Bands</th>
<th>Other Bands</th>
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<td>Communications &amp; Measurements</td>
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evolution of new wireless technologies and applications, and the use of advanced architecture and protocols (e.g., packet radio) may lead to flexible regulations and frequency allocations that enable the co-existence of systems that can offer different wireless services with different allocation status. This may lead to the review of the current spectrum management framework and Radio Regulations.

REGULATORY DEVELOPMENTS

Below is a summary of key regulatory developments relevant to the introduction and use of UWB systems:

- USA: In 2002, the FCC permitted marketing and operation of three types of systems that use UWB technology: radar imaging systems, vehicular radar systems, and communications and measurement systems. The FCC authorized the operation of UWB devices on a license-exempt basis (Part 15) subject to certain operational, frequency, and power restrictions. The FCC defined a UWB device as any device where the fractional bandwidth is greater than 20% or occupies 500 MHz or more of spectrum. The FCC reaffirmed its UWB rules in February 2003.

- Europe: The ECC/CEPT PT SE 24 is investigating the impact of UWB technology and ETSI is drafting a standard on short-range communication devices using UWB technology. Draft emission masks have been developed for indoor and outdoor communications. The maximum e.i.r.p. levels of the CEPT and FCC masks have are identical and have the same value as the licence-exemption level for wireless systems that use other technologies. However, the skirts of these masks are different as shown in Figure 1.

- Canada: The objective of Industry Canada is to draw a good balance between facilitating the introduction of new wireless technologies such as UWB and, at the same time, protecting existing wireless services from harmful interference. There is no regulatory decision yet on UWB in Canada. Industry Canada will consult the Canadian public and develop a national UWB policy.

- Other countries: Singapore expressed readiness to issue experimental permits for UWB applications in specified geographical locations with emission masks relaxed by 10 dB relative to the FCC masks. Japan established an institute for
the development of UWB Standards and also expressed readiness to issue experimental licences for UWB applications. Many other countries are monitoring developments and studying UWB compatibility.

- ITU-R: In 2002, the ITU-R created Task Group 1/8 to carry out studies relevant to the proposed introduction of UWB devices and the implications of compatibility with radiocommunication services. TG 1/8 is tasked with the development of ITU-R Recommendations on:
  - The characteristics of UWB devices.
  - Compatibility between UWB devices and radiocommunication services.
  - A spectrum management framework for the introduction of UWB.
  - Measurement techniques for UWB emissions.

The World Radio Conference, WRC-03, approved a Resolution not to consider UWB devices as Industrial, Scientific, and Medical (ISM) applications [5].

STANDARDS DEVELOPMENTS

The IEEE high-rate task group 3 (IEEE 802.15.3a) is considering UWB as a candidate technology for a standard for WPANs. Some UWB companies prefer a standard based on multiband implementation, which divides the band 3.1 -10.6 GHz into a number of channels instead of a single-band (single channel) implementation [6].

From a spectrum management perspective, multiband implementation could help reducing potential interference to both UWB systems and conventional systems. In addition, it may enable avoiding certain frequency bands (e.g., EESS and Radioastronomy bands), which could mitigate some of the difficulties associated with the introduction of UWB.

SUMMARY

This paper introduced the current spectrum management framework and presented the proposed frequency bands for UWB applications. In addition, this paper addressed challenges that face the introduction of UWB technology. It also summarized current UWB regulatory developments, and presented the status of a UWB standard for wireless personal area networks.

The introduction of wireless UWB applications represents a challenge to traditional spectrum management. The evolution of new wireless technologies and applications such as UWB, and the convergence of some wireless service boundaries and markets, may lead to flexible regulations and frequency allocations that enable the co-existence of systems that can offer different wireless services with different frequency allocation status.

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Software Intensive Systems Safety Analysis

Alan C. Tribble & Steven P. Miller
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ABSTRACT

Two important elements in the avionics suite of modern aircraft are: the Flight Control System (FCS) and the Flight Management System (FMS). The FCS provides the capability to stabilize and control the aircraft, while the FMS is responsible for flight planning and navigation.

A clear trend in the aerospace industry is to place greater reliance on software systems, and many FCS and FMS subsystems are implemented primarily in software. For example, within the FCS is the Flight Guidance System (FGS) that generates roll and pitch guidance commands. Similarly, within the FMS is the Vertical Navigation (VNAV) function that acts like a third crew member in the cockpit, ordering mode change requests and resetting target altitude values to enable the aircraft to track the vertical flight plan.

We have developed formal, executable models of the requirements for the mode logic of a FGS and for portions of the VNAV functionality. We have also conducted a comprehensive software safety analysis on the FGS mode logic model, and are completing the analysis of the VNAV model. This analysis uses as its starting point several “traditional” safety analysis techniques such as a Functional Hazard Assessment (FHA), a Fault Tree Analysis (FTA), and a Failure Mode Effects Analysis (FMEA). However, we are also using formal methods techniques known as model checking and theorem proving to verify the presence of safety properties in the model.

This paper summarizes the (now completed) safety analysis that was performed on the FGS model, and highlights the similarities and differences with the (still on-going) safety analysis of the FMS model. In particular, we summarize progress made to date in the use of formal methods to verify the presence of the required safety properties in the models themselves.

INTRODUCTION

The Problem Domain

One of the challenges to investigating the feasibility and cost effectiveness of new software safety analysis techniques is developing a realistic model of a system that reflects the complexity of an actual product. The aviation domain provides several excellent candidates and the avionics system of a typical regional jet aircraft was chosen because of its safety critical nature and its inherent complexity. As Figure 1 shows, the avionics architecture is comprised of many individual systems. The gray boxes indicate those systems that are mainly non-electronic, (i.e., little software) in nature. The white boxes indicate those systems that are electronic, and often have high software content like the Flight Management System (FMS) and the Flight Control System (FCS). The FMS is decomposed into discrete and continuous elements called the mode logic, the control laws, and the flight plan. The FMS mode logic is a set of discrete algorithms that determine when the FGS should change modes of operation. The control laws are continuous trajectory calculations that compare the measured state of the aircraft (position, speed, attitude, altitude), to the desired state and generate guidance commands to minimize the difference between the two. Finally, the flight plan is defined by the flight crew and specifies the desired trajectory of the aircraft, based on adherence to constraints on altitude and position. The FCS also contains mode logic and flight control laws, known as the Flight Guidance System (FGS), in addition to the Flight Director (FD), Auto-Pilot (AP), and Auto-Throttle (AT). Other elements, not shown, may include a yaw damper and auto-trim.

The FGS is a software function that generates roll and pitch values used to control the aircraft, and was selected as the example for our analysis. The FGS is decomposed into discrete and continuous elements called the mode logic and the flight control laws, respectively. The flight control laws compare the measured state of the aircraft (position, speed, attitude, altitude, to the desired state and generate guidance commands to minimize the difference between the two. The mode logic selects the appropriate flight control laws for use anytime the system is active. In contrast, the FMS is responsible for a more diverse set of functions ranging from flight planning to navigation.

Accident Model

Although thorough knowledge of the nature of accidents is not necessary to appreciate the value of our results, a high level understanding is helpful to see how this same approach could
be applied in a larger context. Underlying our analysis is an assumption about the nature of accidents as shown in Figure 2. The definitions used in this accident model are in general agreement with IEEE standards [1, 2]. In brief, an error may be manifested as a fault, a fault may result in a failure, a failure may place the system in a hazardous condition, and a hazardous condition may result in an accident.¹

Our safety analysis therefore focuses on defining the hazards, failures, faults, and errors that could lead to accidents. As shown later, our analysis will use a combination of standard techniques, (e.g., Fault Tree Analysis and Failure Modes, Effects, and Criticality Analysis), in combination with non-traditional, yet very powerful, formal methods techniques.

SOFTWARE SAFETY ANALYSIS

Specifying the Requirements

A specification of the FGS mode logic, and portions of the VNAV function, has been generated in a formal language, the Requirements State Machine Language without Events (RSML*). RSML* is a synchronous language developed for specifying the behavior of process control systems [3]. RSML* runs in the "Nimbus" environment developed by the Critical Systems Research Group at the University of Minnesota. The environment provides a framework for the development of software for safety critical systems, including simulation and visualization. In particular, the Nimbus environment includes a graphical user interface for the simulation engine. An advantage of RSML* is that it is executable. That is, a user may provide inputs and watch how the state machines respond. This makes it ideal for use in a model-based development environment where the requirements themselves can be verified early in the design and development process, while the cost of correcting them is still low. Another important advantage is that RSML* possesses a precise formal semantics so that the models can be formally analyzed.

The predecessor to RSML*, RSML was heavily influenced by Statecharts and uses a similar notion of explicit event propagation. RSML was used to specify the Traffic Collision Avoidance System II (TCAS-II) and the RSML model was ultimately adopted by the FAA as the official specification for TCAS-II. As its name implies, RSML* eliminates the use of events and its semantics have been fully formally defined. RSML* is in most respects similar to SpecTRM-RL, developed by the Safeware Engineering Corporation, but has a slightly different syntax and underlying philosophy.

DEFINING THE SAFETY PROPERTIES

The next step in the safety analysis process is to formally define those properties of the software associated with safety. Safety properties were generated via a Bi-Directional Analysis

¹ It should be noted that not every accident will be initiated by an error. The initiating event may be a fault, as in the case of a single event upset (SEU) in electronic devices, or a failure, due to the wear-out of hardware devices.
(BDA) technique [4, 5]. The starting point for the BDA is the list of hazards. Top-down analysis is then used to trace the hazards down to the related errors. To close the loop, an independent bottom-up analysis is used to trace the errors back up to hazards.

Functional Hazard Assessment (FHA)

Safety is a system level problem and aviation safety standards ARP 4754 and ARP 4761 specify that safety analysis be performed both at the aircraft level and at the system level [6, 7]. The aircraft level hazards are generally few, such as loss of control. If the loss of control hazard is examined, it can be found that failures in a number of systems, (e.g., hydraulic lines, control yokes, flight control surfaces), could give rise to it. These hazards will derive from functional failures and are defined in a Functional Hazard Assessment (FHA).

We started with the functional requirements for the system in question. Examining the consequences of the system failing to provide this functionality identified the hazards associated with the function. Each of these hazards was then assigned a level of criticality in accordance with DO-178B and MIL-STD-882 [8, 9].

We have completed the FHA for both the FGS mode logic and VNAV models. The FGS mode logic analysis is complete, [10, 11], while the VNAV analysis is still being refined [12]. As such, the majority of our discussion will focus on describing the results from the analysis of the FGS mode logic model. After completing this analysis, we identified four Level C (Major) hazards. Because Level C is the most critical hazard, the FGS is considered a Level C system. (In comparison, VNAV is usually considered a Level B system.) The FHA for the Level C hazards is shown in Table 1.

Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) is a top-down analysis technique used to identify the contributing elements (errors/faults/ failures) that could precipitate the system level hazards identified [2, 13]. FTA is a feed-back technique in that one starts with the system level hazards and attempts to work backward by identifying all possible causes of the hazards. Although the name implies that the technique is limited only to "faults," it should be emphasized that FTA is a general, visual technique used to trace higher level events (such as hazards) down to their contributing events. These contributing events could be failures, or errors, in addition to faults.

In an actual aircraft program, the FTA would start with the system level hazards; for example, Loss of Control, and include all aircraft systems that could potentially contribute to such a hazard. For our purposes, the FTA will start with the hazards identified in the FHA. For example, the FTA associated with the hazard "Incorrect Guidance" is shown in Figure 3. Note that because safety is a system level property, the FTA must include elements that input information to the FGS, such as the Flight Control Laws (FCL), and elements that the FGS outputs information to, such as the AP or FD. By performing a FTA on each of the four hazards listed in Table 1, we obtained a listing of twenty-three (23) possible events that could contribute to hazardous conditions. Of these, eight (8) were relevant to the FGS mode logic.

Failure Mode Effects Analysis (FMEA)

To check the results from the top-down FTA, we conducted a bottom-up Failure Mode Effects Analysis (FMEA). FMEA is a feed-forward technique in that the starting points for the analysis are possible errors which are then traced forward to see if they have any impact on system safety (i.e., if they lead to potential hazards) [2, 13]. As with the FTA, the term FMEA should not imply that the results are limited to "failures." FMEA is a general analysis method that flows errors (or faults or failures) forward to hazardous conditions.

The output of a FMEA is a tabular presentation that lists: 1) failure mode (error); 2) effects (hazard); and 3) analysis (interpretation). The starting point for the FMEA was the list of errors derived from Table 1. Many of these errors are associated with hardware or are dependent on malfunctions in other systems and were considered out of scope for this software safety analysis. In this instance, the FMEA did not uncover any new failures but rather confirmed the results generated by the FTA. This is one of the advantages of BDA; tracing through the accident process in both directions gives higher confidence in the final results.
### Table 1. The Functional Hazard Assessment Identified Four Level C Hazards

<table>
<thead>
<tr>
<th>Functional Failure (Hazard)</th>
<th>Critical Operational Phase</th>
<th>Aircraft Manifestation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect Guidance</td>
<td>Approach</td>
<td>Gradual departure from references until detected by flight crew during check of primary flight data resulting in manual disconnect and manual flying.</td>
<td>No Difference to the AP Between Loss of Guidance and Incorrect Guidance.</td>
</tr>
<tr>
<td>Incorrect Mode Indication</td>
<td>Approach</td>
<td>Gradual departure from references until detected by flight crew during check of primary flight data resulting in manual disconnect and manual flying.</td>
<td>Assumes guidance values are correct.</td>
</tr>
<tr>
<td>Incorrect Indication of Flight Guidance Transfer State.</td>
<td>All</td>
<td>Incorrect &quot;Pilot Flying&quot; side indicated. Possible gradual departure from references until detected by flight crew during check of primary flight data resulting in manual disconnect and manual flying.</td>
<td>Departure from references occurs only if pilot flying and pilot not flying have selected different navigation sources.</td>
</tr>
<tr>
<td>Incorrect AP Engagement Indication</td>
<td>Approach</td>
<td>If engaged, engagement noticed by resistance to control column / wheel inputs. If disengaged, departure from references noticed during check of primary flight data. Result is manual disconnect and manual flying.</td>
<td>Assumes AP disconnect remains operational</td>
</tr>
</tbody>
</table>

### Safety Properties

The eight categories of software errors that were in scope were further examined, to identify the specific properties of the software that could produce the higher level events. For example, in the final model it was seen that there were forty-one (41) separate functional properties associated with the “Error in Annunciation Logic” category. Nine (9) of these “functional” requirements are truly “safety” properties in that violating them may place the system in a hazardous condition. Special emphasis should be placed on verifying these properties that relate to safety.

As shown in Table 2, the FGS mode logic model contained 293 distinct functional requirements, or functional properties. The safety analysis showed that 155 of these “functional” properties were truly “safety” properties that could result in one of the four Level C (Major) hazards identified. We believe that the analysis to this point is unique in that this level of detail is not usually conducted on Level C (or Level B) systems. However, we have also taken our analysis to an even higher level by expanding it to include Formal Methods techniques as discussed in the next section.

### FORMAL METHODS APPROACH

The term Formal Methods refers to a variety of mathematical modeling techniques applicable to computer system (software and hardware) design. In much the same way that aeronautical engineers make use of computational fluid dynamics (CFD) to predict how a particular airframe design will behave in flight, computer scientists may use formal methods to predict the behavior of software or hardware. Two of the most popular formal verification tools are: model checkers and theorem provers [14, 15].

Theorem proving is a technique where both the system and its desired properties are expressed as formulas in mathematical logic. Proving a theorem is simply the process of verifying the existence of a mathematical property from the specifications of the system. Although in principle all proofs could be done manually, it is more effective to use machine based theorem provers to tackle larger, more realistic problems, such as the FGS mode logic or VNAV.

Model checking is a technique that relies on building a finite model of a system and checking that a desired property holds in the model. Checking a model is the process of performing an exhaustive state space search, which is guaranteed to terminate if the model is finite, to look for examples that do not meet the property desired. If a counter-example is found, it is known that the property does not hold.

The use of formal methods in assessing software safety involves four steps. First, the software itself must be specified in a formal language. Second, the safety properties must also be defined formally. Third, both the specification and the
Table 2. A Total of 142 Safety Properties were Identified for the Mode Logic

<table>
<thead>
<tr>
<th>Safety Property Category</th>
<th># of Properties</th>
<th>Incorrect Guidance</th>
<th>Incorrect Mode Indication</th>
<th>Incorrect Indication of Flight Transfer State</th>
<th>Incorrect AP Engagement Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error in Annunciation Logic</td>
<td>41</td>
<td>-</td>
<td>9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Error in FD Selection Logic</td>
<td>13</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Error in Pilot Flying Transfer Logic</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>Error in Independent / Active Logic</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Error in AP Engagement Logic</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Error in Mode Selection Logic</td>
<td>166</td>
<td>-</td>
<td>104</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Error in Synchronization Logic</td>
<td>50</td>
<td>-</td>
<td>23</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total # of Properties</strong></td>
<td><strong>293</strong></td>
<td><strong>5</strong></td>
<td><strong>141</strong></td>
<td><strong>4</strong></td>
<td><strong>10</strong></td>
</tr>
</tbody>
</table>
Using the processing speed and memory of modern computing systems makes the theorem prover capable of rigorously dealing with much larger and more complex problems than the human mind can, but the reasoning process is for the most part still guided by the human user. For example, the theorem prover may try to prove a lemma by induction, only to generate different subgoals that must be proven individually before the proof can be completed. The user must provide guidance on what rules of inference should be used, and in what order they should be applied, for the theorem prover to complete the task.

To date, we have succeeded in proving many properties for both the FGS model logic and VNAV models. The results confirm the advantage of using theorem provers for problems of this nature, but also highlight the difficulties in transitioning the results from the laboratory to a production environment. We are confident that the theorem prover is capable of discharging all properties (provided we have indeed constructed the models correctly) and we are continuing to investigate methods that will speed the analysis so that other programs can benefit from our results.

SUMMARY AND CONCLUSIONS

We have constructed formal, executable models of two complex, embedded software systems – the mode logic of a Flight Guidance System and the Vertical Navigation function. Having the ability to simulate the models helps to verify the correctness and completeness of the requirements and is also a starting point for further model-based development. In order to identify the properties of the software that are related to safety, we then conducted a thorough software safety analysis using standard techniques such as Functional Hazard Assessment (FHA), Fault Tree Analysis (FTA), and Failure Mode Effects Analysis (FMEA). To verify that the model does indeed contain the safety properties required, we then conducted an extended software safety analysis on the design requirements using two formal methods techniques: model checking and theorem proving. In particular, we have used a model checker to show that almost 300 functional (and safety) properties associated with the FGS mode logic are mathematically verifiable properties of the model. We have also used a theorem prover to verify a smaller number of properties for both the FGS mode logic and VNAV models.

We have found the use of formal requirements modeling, in conjunction with Bi-Directional Analysis and formal methods analysis techniques, to be a cost-effective and flexible approach to the issue of software safety. In particular, we were impressed with the power of model checking as applied to this example. This lends credence to the belief that such approaches may become an integral part of future model-based development efforts [18].

ACKNOWLEDGEMENTS

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26
Low-Cost Ground-to-Ground Mobile Telemetry Link

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ABSTRACT

A frequency modulated UHF telemetry link giving 5 MHz of baseband capacity with carrier to noise ratio exceeding 30 dB is described. The system is intended for ground mobile use and provides more than 1 km of coverage also in moderately obstructed terrain indicating allowable maximum path loss up to 110 dB. The mobile transmitter end uses a sturdy flexible antenna. Typical sensor signals include voltage outputs from accelerometers, strain gauges, and thermistors, but live broadcasting-quality television is also easy to implement. Digital interfacing is accomplished through suitable D/A converters, multiplexers, and coders. Both the transmitter and receiver utilize commercial-off-the-shelf building blocks in order to keep the total cost within acceptable limits.

INTRODUCTION

Very often various field tests of mobile ground systems, such as measurements of on-board electronics of vehicles, documentation of chassis and suspension vibrations, and engine performance recordings call for flexible, reliable, and easy-to-implement telemetry radio equipment. Sometimes the motivation to use remote measurements comes from safety regulations or from a wish to protect precious instruments from outdoor temperature extremes. In these situations, we could use copper or optical cables, but there are also cases where realistic platform motion is mandatory and cable transmission is thus very cumbersome or totally impossible. Often the phenomena of interest are simply too far away for any sensible cable connections [1]. Desired telemetry link characteristics include uncomplicated interfacing with a multitude of sensors and data sources, (sometimes of unknown origin) in the transmitter part and sufficient transmission capacity. Mounting space is often limited and tailor-made input circuitry is normally unavoidable thus making complete commercial links less favorable. Contrary to airborne telemetry applications, see [2, 3], ground links seldom need extended geographical coverage, but on the other hand, cannot rely on the positive influence of elevated transmitter platforms. Multipath fading due to surface reflections tends to cause severe complications. This paper describes the design and construction of a wide-band frequency modulated link, which allows direct connection of conventional analog sources such as voltage type sensors (acceleration, force, temperature), a video camera

![Graph showing Signal-to-Noise ratio as a function of Carrier-to-Noise ratio with different peak deviations.]

Fig. 1. Calculated S/N in a frequency modulated system as a function of Carrier-to-Noise ratio (C/N) with different peak deviations

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Fig. 2. Gain (upper), noise figure (lower) and output power curves for a fictitious commercial amplifier block in the 100 to 1000 MHz range.

Fig. 3. Calculated RX input power for 1 km (0.6 mile) hop as a function of frequency if constant antenna gain and 1 W TX output are assumed (solid line) or if the size is fixed (dotted lines).

or a more sophisticated D/A converter block with its built-in coder and multiplexer.

**DESIGN PRINCIPLES**

Even after numerous digital modulation schemes have become ubiquitous, simple analog frequency modulation stands strong [4] and provides a relatively easy way of getting reasonable demodulated signal quality in adverse conditions. This is illustrated in Figure 1 where the obtainable, post-detection signal-to-noise ratio (S/N) is plotted against available carrier-to-noise (C/N) values using peak deviation as a parameter. Naturally, the threshold value above which improvement in S/N gets slower, depends on the applied circuit concept. Although it looks as if we were able to achieve an unlimited S/N just by increasing deviation, this is not possible in reality due to spectrum allocations and the fact that wide modulation bandwidths require appropriate pre-detection filters whereby the C/N gets lower.

Typically ground-to-ground telemetry links have to operate under severe and varying propagation path loss due to multipath fading, vegetation, and topographic shadowing. Therefore carrier frequencies allowing at least some foliage penetration, that is the lower parts of the VHF spectrum, could be attractive. On the other hand, if a truly low-cost design is
aimed at, without any substantial circuit-level design and building activities, commercial-off-the-shelf items should be preferred. A brief look in manufacturers’ data sheets and catalogues soon relieves that readily available amplifier and oscillator devices cover frequencies, say, from 1 MHz up to 1 GHz, possibly extending up to 3 GHz but only if an increase in the average price level is accepted. Modules of well-known companies seem to cover (with a single physical device) a band of 100 to 1000 MHz providing roughly flat gain, noise figure, and output power values as illustrated in Figure 2, and thus a parametric system design approach is possible. Figure 3 shows the receiver input power for our test scenario as a function of operating frequency if we assume free space conditions, constant antenna gain, and transmitter output power. Naturally the situation is somewhat different if we fix the physical antenna size, as can be seen in Figure 3. Nevertheless, smallest possible antennas are practically always selected for mobile use. At least the moving platform antenna must have an omnidirectional pattern. Foliage attenuation further lowers the input level at higher frequencies from those values indicated in Figure 3.

CONSTRUCTION OF LINK MODULES

One of the problems with frequency modulated oscillators is the combination of wide video (modulating signal) bandwidth and relatively low RF carrier frequency. In our case the solution has been to employ two oscillators and a double
balanced mixer as outlined in Figure 4. The first L-band oscillator is frequency modulated by the sensor waveform. The second unit is tuned in such a way that we get at the mixer IF port a desired difference frequency, suitable for amplification. However, as mixers produce a comb-like spectrum, we have to add a properly dimensioned filter. If the two oscillator frequencies are carefully chosen, we can quite easily work with a simple low pass element. Some attenuation is desirable between mixer and filter because the band-rejected signals would otherwise re-enter the mixer and cause unexpected spurious outputs. Finally we have a cascade of three amplifiers and a relatively loose band pass unit before the antenna connector. The photograph in Figure 5 shows the completed transmitter in a die-cast aluminum housing. A high power DC/DC-converter has been mounted on the right wall, close to the final power amplifier. Some simple electronic circuitry to feed the sensor is visible as well.

As usual, the telemetry receiver has filtering and amplification blocks as first stages. Figure 6 shows how, after conventional down-conversion we have added an AGC loop to the system. A sample of the amplified received signal is split into the detector diode and the DC output from it is amplified by about 40 dB in a dedicated operational amplifier/low pass filter combination. The DC voltage output is used to control the gain of the final IF amplifier through a range of 50 dB. Instead of classical resonator-based discriminators or phase locked loops, we decided to utilize a different FM demodulation method. The two remaining power splitter outputs are connected to a double balanced mixer, acting as a phase detector. A suitably dimensioned transmission line performs the transformation from frequency modulation to phase modulation. After detection, the raw video output is low pass filtered and amplified in order to reach a suitable level for data logger connections. No advanced processing or testing [5] is integrated to the receiver at this stage of development.

Besides noise performance as such, the receiver's two critical parameters are its IF bandwidth and the detector's transfer function. Figure 7 illustrates an approximate approach to selecting a suitable band pass filter. Basically we could use a very large detection sensitivity value but this would compromise linearity, because the double balanced mixer IF output voltage is in this case proportional to the trigonometric cosine of the phase difference, see Figure 8. The shortest transmission line gives perfect linearity but poor sensitivity whereas the 1530-degree line is limited to about 0.12 of relative deviation. Typically the delay line is chosen to cause a maximum phase change of 20...30 electrical degrees at peak frequency deviation [6]. As can be seen in Figure 9, the respective nonlinearity is then around 5%. Figure 10 illustrates the completed receiver, without power supply. SMA-type rigid coaxial extensions are used to connect various blocks due to the very large difference in RF signal levels within the small physical volume. Normal flexible cables might show too high leakage values (inadequate shielding) compared to the 90 dB total gain.

The vehicle end transmitter uses a sturdy monopole antenna. Some directivity is allowed in the stationary

Fig. 11. Measured transmitter output spectrum during modulation

Fig. 12. Example of measured receiver output (upper trace) together with original transmitter data input (lower trace). Link path attenuation is 110 dB

installation and thus the receiver can count on about 10 dB of additional gain.

MEASURED PERFORMANCE

Because the transmitter and the receiver of a telemetry system are naturally designed to work together, there is not very much sense in measuring several parameters of just the receiver. However, a thorough spectrum analysis of the transmitter is mandatory in order to find out any harmful spurious signals that might cause interference in other radio systems. Of course, we are able to define the output power and the deviation during this same test. Figure 11 is an example of true measured spectrum, where the modulating signal has been a high-frequency square wave of suitable amplitude. In fact the final power amplifier is so heavily limited in frequency domain that no output filter is necessary. The harmonics of the carrier
stay 70 dB or more below the wanted UHF output. Finally, Figure 12 depicts the performance of the entire link, showing the modulating waveform going to the transmitter and the obtained receiver output for 110 dB propagation path loss. This measurement confirms the capability of the designed equipment in the foreseen field application involving distances up to 1 km in lightly obstructed line-of-sight conditions.

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Introduction to RF Equipment and System Design,
Wavelet De-Noising for IMU Alignment

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ABSTRACT

Inertial navigation system (INS) is presently used in several applications related to aerospace systems and land vehicle navigation. An INS determines the position, velocity, and attitude of a moving platform by processing the accelerations and angular velocity measurements of an inertial measurement unit (IMU). Accurate estimation of the initial attitude angles of an IMU is essential to ensure precise determination of the position and attitude of the moving platform. These initial attitude angles are usually estimated using alignment techniques. Due to the relatively low signal-to-noise ratio of the sensor measurement (especially for the gyroscopes), the initial attitude angles may not be computed accurately enough. In addition, the estimated initial attitude angles may have relatively large uncertainties that may affect the accuracy of other navigation parameters. This article suggests processing the gyro and accelerometer measurements with multiple levels of wavelet decomposition to remove the high frequency noise components. The proposed wavelet de-noising method was applied on a navigational grade inertial measurement unit (LTN90-100). The results showed that accurate alignment procedure and fast convergence of the estimation algorithm, in addition to reducing the estimation covariance of the three attitude angles, could be obtained.

INTRODUCTION

The inertial measurement unit (IMU) consists of two orthogonal sensor triads, one consisting of three accelerometers, the other of three gyroscopes. Nominally, the axes of the two triads are parallel and the origin is defined as the origin of the accelerometer triad. The sensor axes are fixed in the body of the IMU and are therefore called the body axes (see Figure 1). They form the body frame (b) of the IMU. The first sensor triad outputs specific force along the three axes of the b-frame; the second triad outputs angular rate about the same axes. Both sets of measurements are made with respect to an inertial frame of reference. Inertial positioning, therefore, is based on the simple principle that differences in position can be determined by a double integration of acceleration, sensed as a function of time, in a well-defined and stable coordinate frame. However, the practical implementation of the concept is rather complex. It requires the transformation between a stable Earth-fixed coordinate frame, used for the integration, and the measurement frame defined by the sensitive axes of the IMU. The stable Earth-fixed coordinate frame is often chosen as a Local-Level system (East, North, and Up), also called the Navigation Frame (n-frame), and can either be established...
mechanically inside the IMU (stable platform concept) or numerically (strapdown concept) [12].

The navigation parameters (position, velocity, and attitude) are provided in the navigation frame (n-frame) through the transformation from the b-frame to the n-frame using the transformation (or attitude) matrix R_n^b. The relation between the n-frame and the b-frame is realized by continuously updating this transformation matrix. To limit the errors in the derived navigation parameters, it is very important to determine the initial value of such matrix with high accuracy [1]. The process of computing the initial value of R_n^b is known as the alignment of the IMU. Alignment is accomplished by two steps, namely Coarse Alignment (CA), and Fine Alignment (FA). The purpose of the CA is the determination of approximate values of the attitude angles (roll, pitch, and azimuth) between the b-frame and n-frame. The FA, then, refines the CA estimated attitudes using an iterative optimal estimation technique [11].

The CA process is performed using two consecutive processes; leveling and gyrocompassing. Leveling refers to estimating the roll and pitch tilt angles using the accelerometers raw measurements, while gyrocompassing refers to estimating the azimuth angle using the gyroscopes raw measurements. Thus, the obtained accuracy from CA depends mainly on the performance of the inertial sensors, i.e., sensor biases and output noise [10]. On the other hand, the accuracy of FA is affected by random disturbances [9] and, hence, it deteriorates for small Signal-to-Noise Ratio (SNR) cases. In stationary mode, the only signals affecting the IMU accelerometers and gyroscopes are the Earth's gravity and the Earth's rotation rate, respectively. Therefore, for IMUs with gyro whose bias levels are smaller than the value of the Earth's rotation rate (such as navigation-grade and high-end tactical grade IMUs), the analytic CA followed by a FA process is applied to estimate the initial value of R_n^b. However, low-end-tactical-grade (low-cost) IMUs usually use gyroscopes with noise levels larger than the Earth's rotation rate, and, hence, they cannot be aligned in static mode. In this case, external heading measurements using, for example, magnetic compass, are usually used to provide the alignment information [13]. Another possibility is to transfer the obtained attitudes of another, statically aligned, better quality IMU through a master-slave initialization process [5]. In addition, dynamic alignment can be performed through velocity matching techniques by using velocity updates from an aiding system such as Differential Global Positioning System (DGPS) or Doppler radar [5, 14].

**ALIGNMENT OF INERTIAL SYSTEMS**

As mentioned above, the accelerometers specific force measurements (f_x, f_y, f_z) as well as the gyroscopes angular velocity measurements (ω_x, ω_y, ω_z) are referenced to the IMU b-frame. In stationary alignment and neglecting sensor errors, these measurements are related to the Earth’s gravity and rotation rate vectors. The accelerometer and gyroscope measurements are averaged over two or three minutes during the CA procedure to determine initial estimates for the pitch (θ), roll (ϕ) and azimuth (ψ).

Due to the inertial sensor bias errors and measurement noise, the CA cannot provide accurate values for the initial attitude angles that guarantee reliable and precise inertial positioning. Therefore, the FA procedure is utilized to optimally estimate the initial attitude errors as well as the sensor biases and compensate for their effect. This process usually requires about 10 minutes of static data for navigation-grade IMUs. A Kalman filter (KF) is usually used as an optimal estimation tool during the FA process [11]. The observations (updates) for the KF, in this case, are Zero Velocity Updates (ZUPTs). However, the relatively large measurement noise of the inertial sensors, especially for gyroscopes, usually results in a relatively long time for the KF to converge. In addition, the estimated attitude angles may have relatively high estimation covariance.

Accelerometers and gyroscopes have different error characteristics. While accelerometer errors have minor effects on their performance, gyroscope errors usually play an important role in determining the accuracy of the navigation system. In this article, we will be focusing on the characteristics of those errors that can be defined as measurement noises. Other errors like scale factor instability, axis misalignment, and non-linearity are not dealt with in this paper as they can either be calibrated or modeled in the navigation equations.

The noise affecting an accelerometer's signal typically increases with the sensor's bandwidth. It can be characterized as low frequency components (long-term errors) and high frequency component (short-term errors) [15]. Both errors are combined together in the time-domain and affect the accelerometer measurement accuracy. Separation between the two components in the time-domain may assist in improving the performance characteristics of the accelerometer measurements, thus improving the overall accuracy of the navigation system.

Noise contributions in typical gyroscope systems include white noise, correlated random noise, bias instability, and
angle random walk [7]. The sources of these errors differ from one gyro to another. The white noise component is a high frequency component at the output of the gyro. Separation of this noise component by band limiting the gyro output signal can significantly reduce the measurement uncertainty [3]. The correlated random noise is usually characterized by an exponentially decaying autocorrelation function with a finite correlation time [2]. This noise component appears at the low frequency part of the gyro signal and is, therefore, characterized as long-term error [7]. Bias instability of the gyro output is usually due to the system electronics and the inherent structure of the gyro (e.g., discharge assembly in the case of ring laser gyros). Because of its very low frequency nature, it shows up as bias fluctuations in the gyro output measurement. Similarly, random walk is a long-term low-frequency phenomenon and, in the case of optical gyroscopes, it is due to the shot noise and the thermal noise in the photodetector [8]. In fact, it is difficult to separate between those long-term noise components. The correlated noise, bias instability, and random walk are all combined together within a very small frequency band. However, limiting the measurement uncertainties by separating the white noise component will enhance the performance of the gyro.

This article aims at reducing the noise level of inertial sensors measurements by using multi-level wavelet decomposition before using the measurements in the alignment procedure. The objective is to provide more accurate computation of the initial attitude angles in the CA stage and speed up the FA stage while minimizing the estimation covariance of the final attitude angles.

WAVELET MULTI-RESOLUTION ANALYSIS

The last two decades have witnessed the development of wavelets and wavelet analysis, a new mathematical tool which originated in seismology [6] and in a brief period has quickly spread to a whole spectrum of applications in science and engineering fields. The main advantage of wavelet analysis is that it allows the use of long-time wavelet intervals where more precise low-frequency information is needed, and shorter intervals where high-frequency information is sought [16]. Wavelet analysis is therefore capable of revealing aspects of data that other signal analysis techniques miss, such as trends, breakdown points, and discontinuities in higher derivatives and self-similarity [16]. Wavelets are also capable of compressing or de-noising a signal without appreciable degradation of the original signal [3].

In general, the wavelet transformation of a time-domain signal is defined in terms of the projections of this signal into a family of functions that are all normalized dilations and translations of a wavelet function.

Wavelet Decomposition

In discrete time domain, the implementation of the wavelet transform is based on a bank of discrete time filters that have essentially half-band lowpass and highpass characteristics (see Figure 2). Since the inertial sensor dynamics during the static alignment procedure are usually represented at the very low frequency portion of the signal, the measurements can, then, be processed with wavelet decomposition to separate these frequencies from other disturbances. The input signal is basically decomposed into two parts. The first part is called the approximation of the input signal. This part is the output of the lowpass filter of the wavelet decomposition, and thus includes the Earth’s gravity and rotation rate frequency components, in addition to the long-term noises and some highly attenuated short-term noise components. The second part is called the details of the input signal. This part is the output of the highpass filter of the wavelet decomposition. It contains the high frequency noise component of the SINS signal and other disturbances.

Consequently, if several levels of decomposition are utilized, the white noise component can be separated, thus reducing the measurement uncertainty. The approximation will, therefore, contain the Earth’s rotation rate or gravity frequencies, as well as long-term inertial sensor errors. Since both effects are mixed together within very small frequency band at low frequencies, wavelet decomposition may not be able to separate the Earth’s rotation rate or gravity components from the long-term sensor errors. However, such long-term errors have minor effects on the performance of inertial sensors during the alignment process. In addition, these errors can be now accurately modeled using stochastic processes, especially after being separated from the white noise component of relatively high standard deviation.

Choice of the Proper Level of Wavelet Decomposition

In terms of wavelet transformation, the approximation represents the high scale, low frequency part of the inertial sensor measurement, while the details are the low scale high frequency component of the same measurement. The cutoff frequency of the lowpass filtering stage inside the filter bank, shown in Figure 2, is exactly at one-half of the maximum frequency of the measurements signal. For example, if the inertial sensor has a sampling frequency f_s, then the highest frequency component that may appear in the measurement is f_s/2. Therefore, if we apply wavelet transformation to this signal, the approximation will include those components that have frequencies less than f_s/4. The decomposition process can be iterated with successive approximation being decomposed, in turn, so that the inertial sensor measurement is broken down into many lower-resolution components. This procedure is known as wavelet multiple-level decomposition. Figure 3 shows a three-level wavelet decomposition tree.

Theoretically, since the decomposition process is iterative, it can be continued indefinitely. Practically, the decomposition can only proceed until the individual details consist of a single frequency. However, in practice, a suitable number of levels of decomposition are selected based on the nature of the signal or on a suitable criterion [15]. For example, the data rate of the inertial sensors of the LTN90-100 Strapdown INS system (SINS) is 64 Hz (f_s = 64Hz). Therefore, six levels of decomposition will limit the frequency band to 0.5 Hz (f_s / 64). We have determined that 6 levels of decomposition are
1. Decompose the signal with a specified wavelet, to a chosen level (the 6th level in this study).

2. Use a threshold on the detail coefficients at each level to decide which coefficients should be passed through [16].

3. Reconstruct the signal using the wavelet coefficients that have been passed through at each level.

**MODIFIED ALIGNMENT PROCEDURE**

The de-noising method, described previously, helps in reducing the measurement noise of the inertial sensors, thus

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**Fig. 4. Block Diagram of the Modified Alignment Procedure**

Providing more accurate coarse alignment. However, fine alignment procedures based on the Kalman filtering algorithm is still applied to improve the estimation accuracy. The modified alignment procedure starts with de-noising the inertial data with several levels of wavelet decomposition. The number of decomposition levels is chosen to attenuate the noise component while keeping the useful alignment data. A block diagram of the alignment procedure is shown in Figure 4. The proposed de-noising methodology helps Kalman filtering...
Table 1: The LTN90-100 IMU Specifications

<table>
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<th></th>
<th>Accelerometers (1σ)</th>
<th>Gyrosopes (1σ)</th>
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<td>Bias</td>
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<td>0.01 deg/h</td>
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<tr>
<td>Scale Factor</td>
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<td>5 ppm</td>
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<tr>
<td>Random Bias</td>
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<td>0.025 deg/h</td>
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...to converge faster during the fine alignment stage and to provide better estimate of the initial attitude angles as shown in the next section.

RESULTS AND DISCUSSION

De-Noising Inertial Sensor Measurement

The proposed de-noising method was applied to a real data collected from the LTN90-100 navigational-grade IMU in static mode. The LTN90-100 consists of three ring laser gyroscopes and three accelerometers mounted in three mutually orthogonal directions. The specifications of the LTN90-100 IMU are given in Table 1.

The inertial sensor measurements were de-noised with six levels of decomposition to limit the output noise. Since the LTN90-100 measurements are provided at a data rate of 64 Hz, the six decomposition levels limit the frequency band of the original signal from 32 Hz to 0.5 Hz, thus suppressing most of the high frequency noise (short-term errors) existing in the inertial sensor measurements. We decided to stop the decomposition procedure at the 6th level to avoid removing part of the Earth's rotation or Earth's gravity components. Figures 5 and 6 show the LTN90-100 specific force and angular velocity raw measurements before and after the de-noising process. It is evident that most of the noise components are removed, thus reducing the measurement uncertainty. Table 2 lists the standard deviation of the measurement noise of each inertial sensor for both the original measurement and the corresponding approximation at 6th level ($A_6$) of wavelet decomposition. The table clearly indicates that significant reduction in the measurement noise was achieved. The de-noising procedure was specifically beneficial in improving the SNR of gyro measurement from about $-20$ dB to $50$ dB (SNR = $10 \log [\text{signal amplitude} / \text{noise standard deviation}])$.

Coarse Alignment

After de-noising the inertial sensor measurements, the coarse alignment was performed to calculate the pitch, roll, and azimuth angles using equations 3, 4 and 5, respectively. Figure 7 compares the pitch and the roll angles as computed from the raw and de-noised measurements, respectively. Figure 7 clearly indicates that the results of the de-noised data have much less standard deviations (0.0028° instead of 0.177° for the pitch and 0.0018° instead of 0.15° for the roll). On the other hand, the azimuth could not be accurately estimated with the raw measurements, (see Figure 8). The azimuth computation was entirely jeopardized due to the high noise level of the gyro measurements. The mean value for the azimuth angle was determined as $-184.43°$ with a standard deviation of $55.5°$ while the reference value of the azimuth was $-170.9°$. On the other hand, the de-noised data provided an azimuth with mean value of $-171.1°$ (i.e., azimuth error of 0.2°) and a standard deviation of 0.4°.
Table 2: The Standard Deviations of Inertial Sensor Measurements
(Before and After Wavelet De-Noising)

<table>
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<tr>
<th>Inertial Sensor Measurement</th>
<th>Mean Value</th>
<th>STD Before Any Processing</th>
<th>STD after Wavelet 6th Levels of Decomposition</th>
<th>Units</th>
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</thead>
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<tr>
<td>( \omega_x )</td>
<td>-9.576</td>
<td>187.096</td>
<td>0.0491</td>
<td>(^\circ/\text{hr})</td>
</tr>
<tr>
<td>( \omega_y )</td>
<td>-1.075</td>
<td>172.440</td>
<td>0.0202</td>
<td>(^\circ/\text{hr})</td>
</tr>
<tr>
<td>( \omega_z )</td>
<td>11.872</td>
<td>196.880</td>
<td>0.0430</td>
<td>(^\circ/\text{hr})</td>
</tr>
<tr>
<td>( f_x )</td>
<td>-0.081</td>
<td>0.0243</td>
<td>0.0003044</td>
<td>m/s(^2)</td>
</tr>
<tr>
<td>( f_y )</td>
<td>-0.089</td>
<td>0.0300</td>
<td>0.0004800</td>
<td>m/s(^2)</td>
</tr>
<tr>
<td>( f_z )</td>
<td>9.807</td>
<td>0.0320</td>
<td>0.0002038</td>
<td>m/s(^2)</td>
</tr>
</tbody>
</table>

Fig. 7. The Estimated Pitch and Roll Angles
During Coarse Alignment
(Before and After Wavelet Decomposition)

Fine Alignment
The fine alignment procedure was performed using the University of Calgary’s INS/GPS KINGSPAD™ (Kinematic and Geodetic System for Position and Attitude determination) software package [4]. KINGSPAD can process INS only, GPS only, and INS/GPS data. KINGSPAD implements a Kalman filter, which includes 15 error states – 3 for position, 3 for velocity, 3 for misalignment, 3 for gyro drifts, and 3 for accelerometer biases – (for more details about the formulas and derivation, see [17]. Figure 9 shows the azimuth results as computed from the raw and de-noised INS sensor measurements, respectively, over ten minutes of fine alignment. The figure clearly indicates that de-noising the inertial measurement using the wavelet decomposition dramatically improves the fine alignment results by providing fast and accurate estimation of azimuth. De-noising the inertial sensor measurements provides relatively accurate azimuth value from the coarse alignment, and therefore, fine alignment algorithm was capable of providing an accurate value of the azimuth in a few seconds. On the other hand, without applying wavelet decomposition, the same algorithm could not converge to the exact value of azimuth over the ten minutes of fine alignment.

Fig. 8. The Estimated Azimuth Angle
During Coarse Alignment
(Before and After Wavelet Decomposition)
CONCLUSION

Most of the present inertial alignment procedures suffer from the relatively high noise levels of the inertial sensors measurements. This leads to the requirements of relatively long time for inertial system alignment and may lead to inaccurate estimation of the initial attitude angles. This article suggests a modified alignment procedure which utilized a pre-filtering stage based on wavelet de-noising methods to limit the noise level at the output of each inertial sensor before applying the conventional alignment procedures. Experimental results clearly demonstrated the capability of the new approach to improve the SNR of the gyro measurements from ~20 dB to 50 dB. In addition, the results showed that the modified alignment procedure could be performed in less than 200 seconds and provides more accurate estimation of the initial attitude angles as compared to the results obtained from the non-de-noised data. The proposed technique is highly beneficial in providing fast and accurate alignment of inertial measurement units for several navigation applications.

ACKNOWLEDGEMENT

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Conference Report

11th St. Petersburg Conference on Integrated Navigation Systems

The 11th St. Petersburg International Conference on Integrated Navigation Systems was held by the Scientific Research Center of the Russian Federation – CSRI Elektropribor co-sponsored by the Scientific Council of the Russian Academy of Sciences on Motion Control and Navigation Problems, International Public Association – Academy of Navigation and Motion Control (ANMC), American Institute of Aeronautics and Astronautics (AIAA), Institute of Electrical and Electronics Engineers (IEEE), French Institute of Navigation (IFN), L'Association Aeronautique et Astronautique de France (AAAF).

The Program Committee formed of the leading specialists from Russia, USA, France, Germany, and Italy headed the conference. The Conference was held on a high scientific and organization level. The participants marked the applied nature of the papers and discussions. These days brought an interesting and fruitful exchange of scientific and technical ideas. Specialists from 25 countries attended the conference: Australia, Argentina, Bielorusia, Belgium, Brazil, Canada, China, Czechia, France, Germany, Italy, Malaysia, Mexico, Netherlands, New Zealand, Poland, Republic of Korea, Russia, Saudi Arabia, Syria, Taiwan, UAE, USA, Ukraine, Japan – more than 260 persons from 73 Russian organizations and 62 foreign companies. The program included both plenary and poster presentations. Altogether 69 papers were presented including 29 plenary and 40 posters. Papers were distributed among the sessions in the following way: Session I: Integrated Systems – 33 papers; Session II: Satellite Systems – 15 papers; and Session III: Inertial Systems and Sensors – 21 papers.

The Conference Proceedings containing full texts of plenary papers and abstracts of poster presentations were published in English by the conference beginning and handed to all the conference at registration. The conference languages were English and Russian; simultaneous interpretation was provided.

At the final sitting, the Recognition Awards were handed to the following Program and Organizing Committee members and Session Chairmen: V. Peshekhonov, V. Gusinsky, H. Sorg, L. Camberlein, L. Crovella, D. Loukianov, G. Schmidt, L. Nesenjuk, B. Rivkin, M. Grishina, O. Stepanov, J. Sinkiewicz, Yu. Litmanovich, J. Mark, A. Nebylov and A. Zbratky for their important contributions to the conference organizing and holding.

When the conference was over the Program Committee decided to publish the most interesting papers in the Gyroscopy and Navigation Journal published by the CSRI Elektropribor.

Margaria Grishina

[Editor's Note: Selected papers will appear in IEEE A&E Systems in the future.]

Opening the Saint Petersburg Conference by the Program and Organizing Committees, Academician of RAS, Vladimir Peshekhonov

Closing the conference, L. Camberlein is awarded with a Recognition Award for his contribution into the Conference organizing
Integrated Systems

Mr. L. Camberlein (France) and Prof. L. Nesenjuk (Russia)

Dr. J. Mark, (USA) and Dr. Yu Litmanovich (Russia)

Satellite Systems

Dr. L. Crovella (Italy) and Dr. O. Stepanov (Russia)

Prof. A. Nebylov (Russia) and Prof. A. Zbruisky (Ukraine)

Internal Systems & Sensors

Prof. H. Sorg (Germany) and Prof. D. Leukianov (Russia)

Dr. G. Schmidt (USA) and Prof. V. Gusinsky (Russia)
12th Saint Petersburg International Conference on Integrated Navigation Systems

Sponsor: State Research Center of the Russian Federation, Central Scientific and Research Institute Elektropribor

23-25 May 2005

CONFERENCE TOPICS
Navigation, control and guidance systems, and components; Integrated navigation systems for marine, land and aerospace; Applications; Inertial Systems and Sensors; GLONASS, GPS, Galileo and augmentation systems; MEMS; Algorithms and software; & Testing and metrology

CONFERENCE LANGUAGES
The conference languages are English and Russian. Simultaneous interpretation will be provided.

CONFERENCE PROCEEDINGS
Conference Proceedings will be published and handed out at registration.

SCHEDULE
Each full-length paper will be allowed 20-25 minutes for presentation and discussion. No more than 3 minutes are allowed for presentation of a poster paper at the plenary session; discussion will follow at the posters.

ABSTRACTS SUBMISSION
Abstracts of 300 words in English should be sent by e-mail: erprh@online.ru to the Conference Program Committee.

Please indicate your telephone and fax numbers, e-mail, and mailing addresses.

Abstracts of less than 500 words will not be considered.

IMPORTANT DATES
Deadline for receipt of abstracts is 1 December. The authors of the selected papers will be notified by 15 December 2005. Full texts of papers included in the Conference should be submitted by 1 April 2005. Applications of those interested in participating in the conference should be sent to the Organizing Committee by 15 February 2005.

Final information about the Conference, including Preliminary Program, the Conference Registration Form, and Reservation Forms will be placed on the internet. Send preliminary applications by 1 March 2005.
FROM THE EDITOR-IN-CHIEF

**Systems Now Takes Submissions on the 'Net**

Starting immediately, readers wishing to submit potential articles to us for consideration may do so by using http://sysaes.msubmit.net. This site is parallel to the one used by our society's *Transactions*. Our basic rules for this publication still stand:

- **Short articles** – no more than 5 or 6 pages of published length including all figures;
- **Of interest to a broad spectrum of readers** – not just the specialists;
- **Within the scope of the society interests**, (see inside front cover); and
- **Absolutely no mathematics or mathematical expressions** – rewrite your items until you describe your subject in words.

All submissions will be routed to the appropriate sector editor for evaluation, further reviews, and reworking as necessary. Following acceptance, anything needed for publication will be requested by our production staff.

– Evelyn Hirt

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**Fred Nathanson Memorial Radar Award**

**Nominations Wanted**

Established to grant recognition for outstanding contributions to the radar art, this award, consisting of a plaque and honorarium, is made to recognize a member of AESS who has not exceeded the age of 40 in the year nominated.

Nominees must be a member (in any grade) of IEEE/AESS and must have made outstanding contributions to the radar art; nominations must permit appraisal of the contributions. A nomination (the form can be obtained from: http://www.ewh.ieee.org/soc/aes/NathansonAward/) accompanied by 3 to 5 letters of reference (on web) must reach Michael C. Wicks, Chair, Awards Committee, IEEE/AESS Radar Panel, c/o AFRL/SNRT, 26 Electronics Parkway, Rome, NY 13441-4514, US; no later than December 31, 2004.

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**Warren D. White Award for Excellence in Radar Engineering**

**Nominations Wanted**

Dana White Starr and Warren H. White established the Warren D. White Memorial Fund in 1999 and the Warren D. White Award to memorialize their father. The award, a plaque and honorarium, is to recognize an engineer who has made an outstanding achievement by contributing an advance (or series of advances) to radar engineering technology. The advance, significant, public, and well-known, shall be evidenced by technical papers, inventions, presentations, or products.

Nominees need not be a member of IEEE or AES. Nominations must allow appraisal of the candidate’s contribution(s). To enter a nomination, send a letter with three endorsements by the candidate’s peers, by January 15, 2005, to: Warren D. White Award, c/o Mark E. Davis, Box 176, Trenton Falls Road, Prospect, NY 13435-0176, USA; e-mail: mark.davis@rtaf.mil.

(Complete information about Warren D. White and the Award may be found in this publication, 15, 4 (April 2000), 2-3.)
October 2004

Distinguished Lecturers Program
James R. Huddle, Chairman

All AES Chapters and IEEE Sections are encouraged to take advantage of the AES Distinguished Lecturers Program for their regular or special meetings. We have selected an outstanding list of speakers who are experts in their fields. The AES Society will cover up to $500 of the speaker's expenses for travel in North America, with any remaining amount normally covered by the AES Chapter or Section or by the speaker's organization. For travel outside North America, the AES Society will cover half of the speaker's expenses per trip, up to a maximum of $1500. The procedure for obtaining a speaker is as follows: If a Chapter or Section has an interest in inviting one of the speakers, it should first contact the speaker directly in order to obtain his agreement to give the lecture on a particular date. After this is accomplished, and if the Chapter or Section wishes to request financial support from the AES, it should contact James R. Huddle on (818) 715-3264, F (818) 715-3976, j.huddle@ieee.org at least 30 days before the planned meeting, in order to obtain approval for the financial support. The list of distinguished speakers who have expressed their willingness to speak to Chapters or Sections, along with their organization, topics, and telephone numbers, is given below.

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IEEE A&E SYSTEMS MAGAZINE, OCTOBER 2004
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   COUNTRY
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   Full signature of applicant
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