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Recent Breakthroughs in RF Photonics for Radar Systems

Radar systems require transmission of very high purity signals. Photonics is now mature enough to achieve analog transmission with very low noise, strong immunity, and wide-bandwidth even in harsh environments. We present our recent developments of optimized optical links dedicated to radar and multifunction systems.

Battery-Independent Emergency Illumination With RGB Phosphors

Acrylic resins that emit red, green, or blue (RGB) phosphorescence were fabricated. Mixtures of an organic dye and green phosphor created bright afterglow emission in the spectral region from yellow to red, which was difficult to attain with conventional red phosphors. Rhodamine and kiton were suitable for converting green phosphorescence to orange or red fluorescence. The resins continued to glow in darkness for longer than 3 hours after an excitation lamp was turned off. This long afterglow characteristic of the current dye phosphor mixtures was in remarkable contrast with the fast phosphorescence decay of the conventional red phosphors (10-20 mm). These red afterglow resins improve visibility of emergency signs, and realize warm-colored illumination that provides a sense of security in darkness.

On-The-Fly Location Referencing Methods for Establishing Traffic Information Services

We present different use cases for location referencing. We show how a full service chain for Traffic Information Services could be established and give an overview of the widely used method Traffic Message Channel (TMC). After a discussion about the growing requirements of telematics systems, a new approach to location referencing is presented: the on-the-fly methods. We discuss the difficulties regarding the development of on-the-fly methods and present the AGORA-C method which is currently in the standardisation process. We give an overview of the publicised test results using the AGORA-C method concerning its reliability and applicability. In addition, we present another algorithm for location referencing, MEI-LIN, which focuses on a better identification of a location using topological information of the surrounding road network. An outlook on the current research in Europe shows the main future tasks of establishing location referencing methods.

CWLFM Radar for Ship Detection and Identification

Continuous Wave Lineal Frequency Modulated (CWLFM) radar presents some interesting advantages for coast surveillance and control as well as low probability of interception (LPI). In this paper we present real results obtained with a radar prototype and processed with ISAR techniques. Also, results of an automatic ship identification system applied to simulated ISAR images are exposed. Moreover, radar behavior with unfavorable meteorological conditions is discussed.

Coordinated Continual Planning Methods for Cooperating Rovers

Eight evaluation metrics are used to compare and contrast three coordination schemes for a system that continuously plans to control collections of rovers (or spacecraft) using collective mission goals instead of goals or command sequences for each spacecraft. These schemes use a central coordinator to either: 1) micromanage rovers one activity at a time; 2) assign mission goals to rovers; or 3) arbitrate mission goal auctions among rovers. A self-commanding collection of rovers would autonomously coordinate itself to satisfy high-level science and engineering goals in a changing partially understood environment – making the operation of tens or even a hundred spacecraft feasible.

Selective Combinations in Personal Satellite Navigation

Methods for selecting satellite combinations in personal satellite navigation are presented and categorized. The methods include different algorithms and various data parameters and computed parameters. This paper offers a summary on the topic as well as future considerations.
Recent Breakthroughs in RF Photonics for Radar Systems

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**ABSTRACT**

Radar systems require transmission of very high purity signals. Photonics is now mature enough to achieve analog transmission with very low noise, strong immunity, and wide-bandwidth even in harsh environments. We present our recent developments of optimized optical links dedicated to radar and multifunction systems.

**INTRODUCTION**

The development of airborne and ground-based multifunction systems induces increasing needs for transmission of high dynamic range analog signals and high bit rate signals. This implies that new systems are facing volume and EMC issues for which RF photonics appears as a very promising technology due to its very high potentiality of integration and immunity to electromagnetic perturbations.

In the past ten years, many high quality and reliable optical components have been developed and commercialized, driven by the strong telecom market. At low RF frequencies, commercial modules, realized with these components, achieve performances close enough to our military requirements to be extensively studied. With accurate understanding and modeling of these components, customization mainly focused on RF access and driving

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**Fig. 1. Use of RF photonics technologies for military products;**
**Fig. 1A. Optical links implementation in airborne system for multifunction systems;**
**Fig. 1B. Optical links implementation used in ground-based radar**
boards, full-size experiments lead on flying systems and on full active transmission networks, we have demonstrated that RF photonics are fully mature to be implemented even on our most stringent and exposed systems.

Among the RF signals to be transmitted, we restrict the presentation to local oscillator (LO) signals and pulsed RF signals in emission mode. An optical distribution of these signals shall be implemented either on an airborne, ground-based, or naval radar system with rotating antenna as depicted in Figure 1.

In the frame of multifunction systems broadband microwave photonics links, up to Ku band are envisaged to simplify systems complexity and add performances by using, for example, wavelength division multiplexing. On ground-based radar and naval systems, optical links are used to transmit analog and digital signals between the static part and the rotating antenna and to ensure the distribution inside the antenna at sub-array level and up to each transmit and receive module.

Radar systems require very high purity local oscillators to down-convert the received signal. The foreseen advantages of an optical transmission for LO signals lie both on its intrinsic immunity, as well as its smartness.

The requirements shall be divided in two applications:

- **Ground-based and naval radar systems** requiring narrow band optical links and wavelength division multiplexing due to the rotary joint, with close-to-carrier phase noise floor between –155 dBc/Hz for low frequency LO to –140 dBc/Hz for highest frequency LO relative to S-band applications.

- **Airborne radar systems** that required wide-band optical links operating up to 18 GHz. The demanding dynamic stands around 80 dB.

Environmental tests have been performed; EMC tests following EMC MIL-STD-461 standard, vibrations tests with classical naval or airborne specifications and temperature tests, typically up to –40°C to +85°C.

In this paper, we present the basics of optical links for microwave signals as well as the modeling tool that we have developed. Then we focus our attention on the design of the RF access either of lasers, modulators, or of photodiodes as well as full link considerations like avionic optical connections, and we report on experimental results obtained on optical transmission network demonstrators.

**BASICS AND MODELLING**

Microwave photonics links can be completely described in terms of microwave gain, phase, noise figure, compression ratio, spurious free dynamic range, and phase noise close to the carrier. However such a description relies on a proper understanding of the physical mechanisms occurring within the optical components inserted in the microwave photonics link.

We have developed predicting models for several standard optical devices associated to optical links. It must be noted that these predicting models are not phenomenological, but are based on underlying physical behavior of the component. From these studies, we have designed a software adapted to the simulation of microwave photonics systems. Among many features it offers the possibility of simulating wavelength multiplexed systems as well as impedance matched links (see Figure 2). As opposed to commercially available software, in which the temporal evolution of the signal is computed, we have chosen a spectral-based approach. More specifically, the different parameters are represented in the spectral domain and their evolution along the optical link is computed at the output of each component. This approach allows the spectral bandwidth to be restricted to a given frequency range, enhancing significantly the simulation accuracy and lowering down the calculation time. It is also more compatible with phase noise studies as compared to a time-based approach.
The prediction capability of our software is illustrated in Figure 3 where the noise spectral density of a simple link is plotted. Among all the simulated parameters, we have chosen to present the noise spectral density because its knowledge is essential regarding the dynamic range optimization of the link. In the example of Figure 3, the link includes a directly modulated laser, a 10m-fiber, and a photodiode. We are in a situation where the relative intensity noise (RIN) of the laser is the dominant noise. Hence, one can notice that the maximum value of noise lies at the relaxation oscillation frequency of the laser $f_r$. When the laser polarization current is increased, $f_r$ increases leading to a shift of the noise maximum toward high frequencies, as shown in Figure 3. A very good agreement between the experimental and theoretical results is obtained.

The simulation software being very promising, is continuously upgraded in order to refine its predicting models and to include additional components.

OPTIMISED OPTICAL LINK DESIGN

For wide-band link as well as for narrow-band link, we decided to use direct modulation of the laser diode.

Indeed, directly modulated optical links are very attractive to that end [1, 2], for their easiness of implementation compared to externally modulated optical links. However they suffer from a high loss budget mainly due to strong mismatching at both sides (laser: very low impedance, photodiode: very high impedance). To decrease the losses of these links, we developed matching networks [3] as shown on Figure 4. Two kinds of matching networks are used:

- **Wide-band links**: active matching networks which consist on a trans-impedance distributed amplifier at the laser input and at the photodiode input;

- **Narrow-band links**: reactive matching networks based on fully passive elements.

One of the stringent specifications for airborne systems is the need for a high degree of integration. The use of integrated photo-emitter and photo-receiver provides great advantages. Because for low signal level and high detection dynamic, pre- and post-amplified optical links are needed.

That is why in the same module, we have to integrate amplifier and laser chip or photodiode chip. Impedance matching must be inserted to maintain a high signal to noise ratio over all the Ku-band. Only a Monolithic Microwave Integrated Circuit can ensure this function. We recently achieved a broadband optimized photoelectric link with low losses (less than 10 dB) to cover wideband needs (Figure 5).

![Fig. 5. Integrated emitter and receiver module for wideband applications](image)

![Fig. 6. Available gain using resistive or reactive matching network](image)

External modulation link over Ku-band has also been developed. It was used to remote the signal between an antenna down to a receiver. This link was composed of an electrical amplifier, external modulation source (CW laser and Mach-Zehnder modulator), 50 m optical fiber and a photodiode. The performances of this link are interesting and compatible with the requirements of Electronic Warfare systems: no electrical losses are observed (0 dB gain), and less than 15 dB noise figure have been measured from 0.5 GHz to 20 GHz.

Figure 6 shows the available gain of an analog optical with resistive and reactive matching. The gain of a reactively matched optical link mainly depends on the photodiode equivalent capacitance and on the frequency.

The choice of the photodiode geometry is a compromise between the matched bandwidth and the gain of the link. To design matching network for frequencies below 2 GHz, we use a method based on resonant cells as described in [5]. We determine an $R$, $L$ equivalent circuit for the laser diode and
an R, C equivalent circuit for the photodiode. To reach a return loss better than –10 dB in a 10% bandwidth, we used 4th order bandpass matching network. For frequencies above 2 GHz, the matching is done by a quarter wave transformer. The results are detailed in the next section.

**DEMONSTRATION**

Environmental tests have been made on optical external modulation links and direct modulation link to ensure airborne specifications and constraints. Each link can withstand temperature range from –45°C to +85°C. No degradations have been observed during and after these tests.

Figure 7 shows the available gain of an external modulation in the temperature range from –45°C to +85°C.

The module input compresion point was measured to be of 21 dBm.

Figure 8 shows the frequency response of a direct modulation optical link without amplifier associated with the laser diode (green curve) and with a transimpedance amplifier (Monolithic Microwave Integrated Circuit [7]) which optimize photonic link with low losses (blue curve). The module input compression point was measured to be of 11 dBm.

These broadband microwave links are envisaged to simplify multifunction systems complexity.

**ENVIRONMENTAL TESTS**

Environmental tests have been made on these modules to ensure airborne specifications and constraints. Each module can withstand temperature range from –40°C to +85°C without reduction of performance. They have been tested through Electromagnetic field (200 V/m on Ku band) and shock (0.01 g²/Hz between 10Hz to 1kHz and 0.02 g²/Hz between 1 kHz to 2 kHz). No degradations have been observed during and after these tests.

Figure 9 shows the architecture of the demonstrator for signals distribution in radars with rotating antenna [7].

Four analogue signals are transmitted through the rotary joint:

- LO 1: around 4 GHz with 400 MHz bandwidth
- LO 2: around 1 GHz, CW signal
- LO 3: around 50 MHz, CW signal
- RF: S-band, 400 MHz bandwidth, pulsed signal

A digital signal is added in the opposite way. In fact this digital link is dedicated to the transmission of the analog received signal converted into digital signal inside the antenna.

All the analogue links are reactively matched as described in the section entitled Optimised Optical Link Design. Results obtained concerning the transmission losses and the close to carrier phase noise of the links are summed-up below. The measurements have been carried out on the complete demonstrator. Table 1 summarizes the insertion losses as
Table 1. Insertion losses of the different link in demonstrator configuration, and absolute insertion losses and close to carrier phase noise measured at 1 MHz offset from the carrier

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<th>LO2</th>
<th>LO1</th>
<th>RF</th>
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<tr>
<td>Measured S21 (dB)</td>
<td>-15.5</td>
<td>-16</td>
<td>-31.7</td>
<td>-25</td>
</tr>
<tr>
<td>Optical losses (dB)</td>
<td>8</td>
<td>8</td>
<td>8.4</td>
<td>6.2</td>
</tr>
<tr>
<td>Absolute S21 (dB)</td>
<td>0.5</td>
<td>0</td>
<td>-14.9</td>
<td>-12.6</td>
</tr>
<tr>
<td>L(f) at 1 MHz dBC/Hz</td>
<td>-158</td>
<td>-151</td>
<td>-147</td>
<td>-143</td>
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measured within the demonstrator (including optical losses and the absolute S21 obtained by subtracting these optical losses) and the close to carrier phase noise floor. Note that the losses in optics are converted twice in dB in electrical domain.

As shown in this table, the LO3 and LO2 point to point links have no losses and even little gain for LO3 link. This represents an increase of 20 to 25 dB compared with standard telecom link using resistive matching and corresponds, to our knowledge, to the best RF performances obtained with directly modulated optical links dedicated to these frequencies.

For the RF signal, the close to carrier phase noise spectrum corresponds to a phase stability around 80 dB in 1 MHz bandwidth. A pulse-to-pulse stability measurement has confirmed this value, and shown an equivalent contribution of phase and amplitude noise on the stability.

The reduction of losses provided by the reactive matching network allows reaching the close to carrier phase noise floor (~155 dBc/Hz to ~140 dBc/Hz) and phase stability (80dB in 1MHz) required for LO and RF pulsed signals. Figure 10 shows an example of the close to carrier phase noise for several ambient temperatures.

The link has also been tested though random vibrations (0.01g/Hz from 5 to 100 Hz) and sinus vibrations (1g from 15 to 150 Hz) without degradation of the performances. Moreover, the links are fully compliant with the EMC MIL-STD-461 standard for ground equipments.

Figure 11 shows a comparison between measurement and simulation for the LO2 link. Same results are obtained for other links.

As shown in the figure the measured close to carrier phase noise is very close to the predicted one, that validates our simulation software for analogue optical link.

**CONCLUSION**

Owing to an accurate modeling and the outcome choice of components, to a customized design of the access of optoelectronic devices we have successfully demonstrated that RF photonics is fully mature to be introduced in Radar and EW systems.

Main effort for future work will be paid on higher integration level and cost reduction. Costs are presently quite balanced compared to classical distribution scheme and shall be drastically reduced in a few years with new technology breakthroughs.

**ACKNOWLEDGMENT**

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Demonstration of 0 dB gain reactively machted optical links for very high purity signal distribution in S-band
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Battery-Independent Emergency Illumination
With RGB Phosphors

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ABSTRACT

Acrylic resins that emit red, green, or blue (RGB) phosphorescence were fabricated. Mixtures of an organic dye and green phosphor created bright afterglow emission in the spectral region from yellow to red, which was difficult to attain with conventional red phosphors. Rhodamine and kiton were suitable for converting green phosphorescence to orange or red fluorescence. The resins continued to glow in darkness for longer than 3 hours after an excitation lamp was turned off. This long afterglow characteristic of the current dye phosphor mixtures was in remarkable contrast with the fast phosphorescence decay of the conventional red phosphors (10-20 mm). These red afterglow resins improve visibility of emergency signs, and realize warm-colored illumination that provides a sense of security in darkness.

INTRODUCTION

Recently the world encountered a variety of great disasters such as earthquakes, terrorist explosions, subway fires, and electric power failures. Emergency illumination and directional signs are indispensable in subways, underground passages, and great buildings. These constructions are usually equipped with electric instruments for emergency uses, e.g., emergency generators and lamps, but they do not function if they suffer damage by collapse of the construction. In contrast to these electric instruments, phosphorescent signs and illuminators continue to glow independently of an electric power source for several hours [1]. In addition they are robust against destruction; i.e., even if signboards or illumination panels are broken to pieces, the composing phosphors continues glowing. Phosphorescent signs and tapes are being used widely to indicate stairs and exits in darkness. We have recently developed an emergency illumination panel that displays different pictures depending on room brightness; i.e., a backlit advertisement board changes to a large emergency sign, which shines brightly enough to allow one to read words on paper or to recognize faces [2].

The conventional phosphorescent signs, however, cannot provide sufficient visibility, since phosphorescence is restricted in the shorter wavelength range of the visible spectral region, i.e., green, blue, and purple. On the other hand illumination with the conventional bluish phosphorescence creates eerie environments in which people feel anxiety as if they were in a haunted house. If phosphors with warm colors, e.g., orange or red, can be used in emergency signs, the signs will become much easier to recognize. Also warm-colored illumination will provide people a sense of security in an emergency.

Some researchers have been developing red phosphors, and some companies have placed for sale [3-5]. However, afterglow intensities of these red phosphors are insufficient in comparison with those of the other (green, blue, or purple) phosphors. Figure 1A shows afterglow spectra of the phosphors that are commercially available at present. Although a red phosphor (Nichia, NP2850) exhibited a high phosphorescence peak, a total light intensity was weaker than those of the other phosphors (EZ Bright, EZ(P15, EZCB15, EZCG15) because of a narrow peak-width. Figure 1B shows decay curves of the total light intensities that were measured after an excitation lamp was turned off. Although the red phosphor shined bright during the excitation process, it became dark very quickly after the excitation was stopped.
SAMPLE PREPARATION

In spite of many researchers’ efforts, both the extension of the decay time and the enhancement of brightness were difficult to attain with red phosphors. In this work, we examined wavelength conversion by the use of organic dyes. When organic dyes are excited by blue or green phosphorescence, they emit yellow, orange, or red fluorescence with a high quantum efficiency [6]. Figure 2 shows transmission spectra of red dyes, i.e., rhodamine 6G, rhodamine B, and kiton (Nippon Kankoh-Shikiso Kenkyusho, NKX-1323, NKX-1324, and NKX-1325) that were measured with a 0.05-mM (5 × 10^{-7} mol/l) methanol solution in a sample cell of 10-mm thickness. These dyes have an absorption band in the 450-600-nm wavelength region, which overlaps an emission band of the green phosphor (gray curve). Therefore, if these dyes are dispersed in a solid matrix together with the green phosphor, red afterglow is expected to appear.
We used photocurable acrylate (Maruto, #4111) as a matrix. This resin was transparent over the entire visible spectral region, and did not react with the phosphors and dyes that were used in this experiment. A methanol solution of an organic dye and powder of green phosphor were mixed in a raw solution of the acrylate. A mixing ratio of the methanol solution was changed to prepare samples with various dye concentrations. The phosphor concentration was fixed at 5 vol.%, since the strongest phosphorescence was attained at this concentration. The mixed solution was poured into a polypropylene mold and was exposed to a fluorescent lamp for ~4 hours. Samples prepared in this manner were 30 mm in diameter and 5 mm in thickness.

**EXPERIMENT**

Figure 3A shows an optical setup for measuring emission spectra of the acrylate samples. A sample was fixed in a metal holder, and was exposed to a fluorescent lamp. As Figure 3B shows, this lamp emits fluorescence in the 400-500-nm wavelength region, where the green phosphor has an absorption (excitation) band. A light intensity at the sample surface was ~2 mW/mm². Emission from the acrylate sample was picked up by an optical fiber (core diameter: 1mm) that was placed at the other side of the sample. Emission spectra were measured by using a multichannel spectrometer (Hamamatsu, PMA-11). A sample was excited (lamp exposure) for 5 minutes, and then the lamp was turned off to observe an afterglow process. Spectra were measured at 1-s intervals throughout the excitation and decay processes. All experiments were conducted in a dark box.

Figure 4A shows afterglow spectra that were measured for acrylates with rhodamine 6G and green phosphor. When a concentration of rhodamine 6G was 0.25 mM (gray curve), a weak emission was observed in the 450-550-nm wavelength region (green) beside a strong fluorescent peak of rhodamine 6G at around 580-nm wavelength (orange). This green emission occurred because the dye-concentration was too low to absorb the green phosphorescence completely. As a result of superposition of green and orange emission, this sample looked yellow. The black curve in Figure 4A shows an afterglow spectrum of a sample in which dye concentration was raised to 0.5 mM. The green phosphorescence disappeared in this sample, and consequently the afterglow color changed to orange.

Figure 4B shows afterglow spectra of the samples with rhodamine B. Strong green phosphorescence was observed even when the dye concentration was 0.5 mM (gray curve), and the sample looked yellow. However, when the dye concentration increased to 1.5 mM (black curve), the green phosphorescence was completely absorbed in the sample, and accordingly the emission color changed to orange.

Similar results were obtained as regards the samples with kiton. As the dye concentration increased, sample color changed from yellow to red. When the dye concentration was high enough, the sample looked red rather than orange, since
the fluorescence peak of kiton was located at a longer wavelength than that of rhodamine.

Figure 5A shows a photograph of afterglowing samples. The samples were excited for 5 minutes with the fluorescent lamp. The photograph was taken in darkness 2 minutes after the lamp was turned off. The sample with kiton and green phosphor (left) shined more brightly than that with the conventional red phosphor (right). Phosphorescence from the red phosphor decayed rapidly, and became invisible in 10–20 minutes. However, the fluorescence from kiton was visible for longer than 3 hours.

Figure 5B shows temporary changes in afterglow intensity. This measurement was conducted with the same optical setup as shown in Figure 3A, but the fiber and the spectrometer were replaced by a power meter (Ando, AQ2726). The Si sensor of the power meter was placed at a distance of 5 mm from the sample surface. The light intensities were recorded at 1 minute intervals. Samples measured were the acrylate discs of 5 mm thickness that contained:

- 1) rhodamine 6G (0.5 mM) and green phosphor (5 vol.%),
- 2) rhodamine B (1.5 mM) and green phosphor (5 vol.%),
- 3) kiton (1.5 mM) and green phosphor (5 vol.%), or
- 4) red phosphor (5 vol.%).

Light intensity of the red phosphor became too weak to measure within 30 minutes. By contrast, the samples with dye and green phosphor continued to emit afterglow for longer than 3 hours. Of these dye/phosphor mixtures, the sample containing kiton exhibited the brightest afterglow.

DISCUSSION

Intensity or efficiency of afterglow is related to how efficiently dye absorbs phosphorescence. In addition, it is affected by the extent to which dye interferes with the transmission of excitation light. If dye absorbs the excitation light strongly, phosphor cannot be excited strongly. As Figure 2 shows, kiton is more transparent than rhodamine in the wavelength range below 500 mm, where the green phosphor acquires most excitation energy. This is the reason that the sample with kiton exhibited stronger afterglow than other samples.

In this work, we demonstrated that the RGB light emission continued for longer than 3 hours even after a lamp was turned off. This fact implies that a battery-independent full-color display can be constructed by mixing these three glowers. Actually various colors between yellow and red were sensed by human eyes, when a dye concentration was suitably adjusted (Figure 4). Such a full-color afterglow display will be useful to guide people in emergencies.

CONCLUSION

Afterglow materials that emit red light were fabricated by dispersing organic dye and green phosphor in an acrylate resin. A suitable mixture of kiton and green phosphor created red phosphorescence, which was brighter than that of the conventional red phosphor. Since the decay time of this red afterglow is comparable with those of green and blue phosphors, a full-color display can be achieved even if an electric power system is destroyed. Therefore the afterglow materials that were fabricated in this work seem useful in developing emergency illumination or emergency signs.

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Emergency illumination panel that displays different pictures depending on room brightness,

Long luminescent glass: Tb\(^{3+}\)-activated ZnO-B_2O_3-SiO_2, glass,


Bright afterglow illuminator made of phosphorescent material and fluorescent fibers,
On-The-Fly Location Referencing
Methods for Establishing Traffic Information Services

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ABSTRACT

We present different use cases for location referencing. We show how a full service chain for Traffic Information Services could be established and give an overview of the widely used method Traffic Message Channel (TMC). After a discussion about the growing requirements of telematics systems, a new approach to location referencing is presented: the on-the-fly methods. We discuss the difficulties regarding the development of on-the-fly methods and present the AGORA-C method which is currently in the standardisation process. We give an overview of the publicised test results using the AGORA-C method concerning its reliability and applicability. In addition, we present another algorithm for location referencing, MEI-LIN, which focuses on a better identification of a location using topological information of the surrounding road network. An outlook on the current research in Europe shows the main future tasks of establishing location referencing methods.

INTRODUCTION

More and more drivers in the whole world are longing for good quality traffic information because they are tired of spending so many hours in traffic jams. In Germany, about 18% of the German annual fuel consumption is wasted as a consequence of traffic jams [10]. Telematics systems bear a great potential to avoid traffic jams; especially car navigation systems can support a public traffic management to redirect traffic flows in order to relieve overloaded roads. Thus, the need for systems to collect, gather, distribute, and process traffic information arises in many parts of the world. Different systems are already in use, in many places the installation is in progress. Enhancements of telematics systems are on the way because the needs and the requirements of such systems grow.

To be more specific, let us look at a modern car navigation system. Nowadays routes can be calculated dynamically, which means that updates of the route can occur while you are driving. Therefore, route guidance can also be adjusted to incoming information such as traffic jams, etc. If a traffic event is assigned to a certain path in the road network, a so-called location, this path will be transmitted to the navigation system. In order to avoid the traffic jam, the navigation system then has to be able to identify the affected road sections in its own digital road map. This means that a supplier like a traffic management centre uses a digital road map for encoding the affected road sections into a so-called location reference. The navigation system then has to be able to identify the encoded road section in its own digital road map. We call this procedure the decoding of a location reference.

Fig. 1. Location referencing using TMC location codes

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Location referencing which determines the encoding and decoding process in such a telematics system is an important part for the realisation of a public traffic management system. Nevertheless it bears many difficulties. Why not only use standard postal addresses for referencing points and locations in an urban road network? Why are all these extravagant expenses necessary if we could also use an exact co-ordinate to reference a location? Postal addresses are an old form of location referencing that does not work all the time. Surely, some of us already experienced that a letter could not be delivered because the name of the road or the house number was misspelled. The same would happen with location references based on road names and house numbers only. In case of notation differences, the location could not be exactly identified in the road map. Furthermore, in rural regions house numbers do not exist. Some countries even do not have house numbers in urban regions, e.g., Japan.

A better attempt is the use of co-ordinates, they are available for every place on the world. However, co-ordinates are exact only to a certain extent depending on the precision of the co-ordinate value. Due to rounding errors during the computation of the location reference we will also get deviations up to a few meters. Other difficulties regarding the use of a single co-ordinate will be explained later. As a consequence, more complex location referencing techniques were needed that enable a consistent and reliable way of addressing locations for telematics purposes.

TRAFFIC INFORMATION SERVICES

A traffic management system is required to deliver high quality data. Quality means precise information about what has happened and where. Therefore, the time delay between occurrence of the traffic incident and information of the driver has to be short. In Europe, this is achieved with automated data collection and data processing. Manual input for long-term events like road works, etc., is also possible.

In Europe, drivers are not willing to pay for a service. Costs are the most critical part of the system. Hence, only solutions with an excellent quality of service to cost relation can be successful. A system design for traffic information services should take investment, operating, and transmission costs into account. As a consequence, the system needs to use an up-to-date technology which enables easy updates and maintenance. Public as well as private financing options and operation should be independently realizable.

To establish traffic information services an entire service chain has to be created. The first step is to collect and gather data. A lot of data sources are used to generate traffic messages. Inductive loops and other sensors are integrated in the road network to obtain frequent information. On a voluntary basis, people can call the radio station when they recognise a traffic jam. These so-called jam busters can add traffic data to the information pool. One of the newest technologies is Floating Car Data (FCD) where a fleet of cars is equipped with sensors that distribute certain information. One car of the fleet can be compared to a piece of wood drifting in a river. If you measure speed and travel time of the piece of wood, you will know how fast the river flows. So, the car measures its current travel time and transmits this data to the traffic management centre. There, the data is then processed automatically. The information is aggregated into a picture of the traffic situation. Based on this information, traffic messages can be created and sent to drivers and police cars.

This part of the service chain is the service provision and delivery. Broadcasting via FM, DAB, or DVB-T is the cheapest and best way to inform drivers. To transmit more traffic data per time interval, traffic information is transmitted in digital form, for example, in the so-called RDS/TMC format.

LOCATION REFERENCING USING TMC TABLES

One of the systems for the description and the transmission of traffic information already in use is Traffic Message Channel (TMC) [9]. TMC is very successful and already works fine for most of Europe’s major roads. It is currently being installed in other places of the world because it is an easy and cost-efficient way to establish traffic information services.

TMC is used for broadcasting real-time traffic and weather information. A standard message contains the location, the extent, the traffic event, and the estimated duration of the incident. The traffic event gives details of the incident or weather situation. 2048 different traffic events could be coded. About 1500 event codes are already in use [6] and 500 are reserved for future use. They are stored in the so-called event table, which is a database of codes for different defined traffic events.

The location indicates the position of the incident, e.g., a highway segment or a single point. Each location is represented by a code which is stored in a location table. The same table is used by every TMC-participant – by the police, the traffic management centre, the broadcaster, and the receiver. In a TMC-equipped device, the location table is stored on CD, DVD, or memory card. Therefore, to make this method work, fixed codes have to be integrated in the databases of every map vendor in order to reference and re-identify certain parts of the road network using location tables. The code for a location is represented by a 16 bit value. Currently, the German location table version 4.0 already contains 32,500 locations for referencing the motorway network, the national main roads, and some important parts of urban roads [8]. The specified extent determines the traffic direction affected by the incident and describes those road sections in between two TMC codes that, at least, partly belong to the affected area. The estimated duration of the incident can also be added to the traffic message.

TMC is a standardised protocol and can be distributed via FM-RDS and other media. TMC is coded very efficiently. Only 37 bits per message are needed. The coding is based on
the standardised ALERT-C coding protocol, and with the transmission via FM-RDS a good coverage is obtained.

Data messages are received silently and decoded by a TMC-equipped car radio or navigation system, and delivered to the driver visually or as audio output in the preferred language of the user. TMC messages can be filtered in the receiving system, so that only those relevant to the current route are displayed. Additionally, a TMC-enabled navigation system can offer dynamic route guidance — alerting the driver of a problem on the planned route and calculating an alternative route — to avoid the incident.

Figure 1 shows an example. The location indicated by the dashed arrow is coded using the location code 335. The extent of -3 specifies that the location extends from location code 335 to location code 332. Within this extent the location has a length of 10 km. The solid arrow describes a second location which is bounded by the referenced location code 333 and the location code 335 because of the positive extent of 2. The second location has a length of 3 km. Location codes next to each other need not necessarily be consecutive numbers because predecessor respectively successor information is stored in the location table. In this example, two motorways cross without allowing access to each other. Therefore, two location codes are assigned on the same geometric co-ordinate but for different motorways.

TOWARDS ON-THE-FLY LOCATION REFERENCING

With the introduction of DAB further possibilities arise. TMC has become a standard part of DAB, yet, it cannot make use of the advantage that comes with the higher bandwidth DAB provides. Although TMC is a well-established system there are some limitations. First, there is a size limitation of the location table due to the coding scheme structure and the storage capacity of the receiver. This would become a serious problem, especially if we think about providing traffic messages for urban locations, because the location table would have to be extended tremendously in order to cover urban road networks.

The restricted size of the location table also leads to another deficit of TMC. It assumes that the rest of the road network for which no TMC identifiers exist is not disturbed, possibly leading into the problem that all TMC-supported navigation systems use the same detour. Furthermore, there are problems with the identification of and the agreement on relevant geographic phenomena as well as with the distribution, maintenance, and the ownership of the location tables. Originally, TMC was intended as stand-alone, but is today mostly used in connection with digital road maps. This means that a great effort has to be spent on the preparation of digital road maps by relating map elements with pre-determined locations. Indeed, structural double work is done here with the maintenance of the location tables and the road maps.

With growing demand for traffic services, more use cases for location referencing appear. Taking a closer look into the field of modern telematics applications, we will discover that geographic information is a major part of the information communicated in these applications. Besides traffic jams, there is an increasing demand for communicating geo-information, such as: traffic information in general, emergency/accident location, Yellow Pages, or points of interest.

To give an example, imagine a person that needs information about a nearby petrol station which is open 24 hours. The person could use the navigation system to send a request to a service provider. This provider would then encode the closest position of such a petrol station and the driver could be guided there. This cannot be achieved with the usage of TMC, because with TMC it is only possible to address a whole section between two location codes and not an exact position within.

Therefore, the need for a different approach arose. This approach is a map-based on-the-fly location referencing which works as shown in Figure 2. First, a desired location has to be identified in the sender’s digital road map. This location is encoded, which means that a location reference is created using the information already stored in the digital road map database of the sending system. This means that it does not use pre-coded information like the TMC tables. A traffic message containing the location reference is then sent.

After having received the location reference, it is decoded which means that the referenced location is identified by comparing the encoded information with the information stored in the map database of the receiving system. Last but not least, the end user decides on the further usage of the decoded location, e.g., it can be used for calculating detours, etc.

DIFFICULTIES REGARDING ON-THE-FLY LOCATION REFERENCING TECHNIQUES

Car navigation systems use digital road maps to decode on-the-fly location references. To understand the difficulties of the decoding process, we first need to know how a digital road map is generated, stored, and accessed. Afterwards the difficulties of decoding on-the-fly location references are explained.

Digital road maps are based on analogue map data. According to [7], for Germany the so-called Deutsche
Grundkarte (DGK5) with a representative fraction of 1:5000 and the official topographic map Topographische Karte (TK25) with a representative fraction of 1:25000 are used as the main source for the generation of the German digital road network. These topographic maps provide geometric information like the shape of the roads and the position of geographic objects, e.g., rivers.

The process of converting the analogue map data into digital data is called digitalisation. Because of the complexity of this process, most of the digitalisation work is still done manually. The base map is scanned and used as a background picture. After that, points which reflect the geometric shape of the roads are set to mark the shape of the roads. A straight road only needs two points, one at each end of the road, whereas a curved road needs more points for approximating the curvature.

The selected points which then represent the road network are connected via edges, so that in the end the digital road map is nothing else than a graph. Each edge describes a road section which has a start and an end point, and shape points which give the geometric shape of the edge.

The co-ordinate of every point is stored. Hence, together with the edges the digital road map now contains the topographic information of the road network. The next step is to add edge attributes, e.g., according to the GDF standard [5]. Some examples for GDF attributes are direction of traffic flow, functional road class, form of way, or official name of the road. This additional information is gathered from analogue maps, via field inspection, or from other sources[7].

Car navigation systems mainly use a CD or a DVD as map data storage. A digitalised road map of Germany needs a storage space of more than 10 gigabytes. Obviously, it is necessary to reduce the data amount of such a digitalised road map before it can be used by the navigation system.

On-the-fly location references use the topographic information and the attributes stored in the digital road map. Once a location is encoded, it should be possible to decode this location independently of the provided digital road map. In general, maps of different vendors or different production dates are not exactly the same. Reasons for these differences can be varying accuracy of the digitalisation, different manufacturing methods, and changes of the road network over time. Since manual adjustments are necessary during the digitalisation process, the results inherently differ from each other. So, the main challenge of decoding on-the-fly location references is to cope with the following differences in digital road maps.

Road maps need to be updated frequently, because new roads are built, old roads are closed, or attributes of roads are changed. As a consequence, there are different versions from the same road map vendor in use depending on the production date. For location referencing, the most critical difference in between these versions are roads which only exist in one of the versions. However, also road maps from different vendors published at roughly the same time can comprise more, respectively less, roads than the other.

Some vendors use patterns for special geometries like roundabouts. As a consequence, it can occur that a roundabout in one map is exactly circular, whereas in another map the roundabout was digitalised in its real world geometry which can be elliptically.

So-called complex intersections are another case where digital road maps often show differences. Complex intersections are intersections which consist of more than one point. The opposite is a simple intersection which is represented by only one point. Differences in complex intersections originate from the problem that it is difficult to digitalise the turn lines of a complex intersection. Sometimes, an intersection is represented by a simple intersection in one map and by a complex intersection in another map. The same phenomenon occurs with single-lane and multi-lane roads. Multi-lane roads with more than one lane in one direction can be digitalised with one edge per lane. However, there exists no standardised specification in what cases a road has to be stored with more than one edge in the digital road map. As a consequence, it frequently occurs that one and the same road is represented by a single-lane road in one map and by a double-lane road in another map.

Looking at different digital road maps of the same region it soon becomes clear that co-ordinates alone are insufficient for referencing a certain position in a road network. To illustrate this, two maps of different vendors are shown in Figure 3.

Now, what are the consequences of the differences in digital road maps for our location referencing task? It would
be easy to decode a location reference, if the digital road maps of the sender and the receiving car navigation system were equal. Unfortunately, this constitution will rarely occur. We want to decode on-the-fly location references independently from the road map used for encoding the location, hence, the decoder algorithm has to make up for these differences. This means that, in order to detect if parts of the location reference belong to a road that does not exist in the given road map, the decoder has to be able to identify deformed road shapes, missing and additional roads, and cope with discrepancies in the road attributes.

Besides map differences, restrictions considering the message size of the location reference due to the capacity of the channel used for broadcasting the messages is another major issue we have to consider. As location referencing is used for telematics applications in car navigation systems, we have to be able to transmit traffic messages with position information into the car, e.g., to locate the position of a nearby hotel or a traffic jam. According to first assumptions, for a bigger town several hundred traffic messages can be broadcast at any time. Sent via DAB, a car navigation system will receive all available traffic messages, even if they regard traffic incidents miles away from the car position. Out of these, the car navigation system has to filter out those traffic messages which affect positions on the calculated driving route.

To handle the large amount of data to be sent at any time, a goal determined by the industry is to achieve a message size smaller than 50 bytes for one traffic message [3]. In order to process the incoming messages, a feasible time restriction for decoding the received location references would be to decode the 100 most important messages in less than 3 minutes.

What follows is that we need a method for location referencing which is capable of using topological, geometrical, and attribute-related information in a compact and structured way in order to supply an efficient way of identifying the referenced locations.

ON-THE-FLY LOCATION REFERENCING METHODS

Projects involved in the development of possible coding and decoding algorithms so far were the EVIDENCE (1997-1998) and the AGORA project (2000-2002) [1]. Several partners from the industry participated in these projects. EVIDENCE stands for Extensive Validation of IDENTification Concepts in Europe. During this project, a first approach for on-the-fly location referencing that codes intersections of road maps was tested and validated, the ILOC approach. Subsequently, the so-called extended ILOC approach was developed to overcome some of its weaknesses. For determining the expansion of the location, the extended ILOC approach uses the ILOC codes of the location's bounding intersections.

Due to an unsatisfactory hit-rate of these first approaches, which means that too many location references could not be decoded correctly, the follow-up project AGORA was initiated. The aim of AGORA was to implement a global location referencing approach. During this project, the different partners combined their ideas to find better referencing techniques. Consequently, the extended ILOC approach was merged with the Pivot Point approach from Siemens VDO and the GoodLane approach from Robert Bosch GmbH. The main idea of these approaches was to select special points of the road network and supply them with certain attributes to make them easily identifiable. For a detailed description of these methods, see [1].

Although the AGORA method achieved a hit-rate of 95%, the method was not feasible because the size of such generated traffic messages was too large. The AGORA method uses many points to identify a location and the coordinates of these points need a lot of storage space. Thus, the average message size in the project was 250 bytes, whereas a maximum of 50 bytes would be necessary. Furthermore, the method still had problems identifying the correct side of the road when dealing with multi-lanes, and especially if there were big deviations in the geometry, the correct location could not always be identified.

Although the AGORA method was submitted to the ISO committee in 2002, yet, the standard is still under discussion and development. The requirement to reduce the message size and hence the transmission cost was the motivation for the development of the AGORA-C specification [2] (C stands for compact). Current research also focuses on another approach called MEI-LIN.

AGORA-C

Like the AGORA location reference, an AGORA-C location reference consists of points and road attributes. The AGORA-C specification defines an encoding framework, a logical data model, a set of 31 encoding rules, a coding procedure as guideline for developing an encoder, and a description of the AGORA-C physical format used for transmitting the messages. The difference mainly lies in the data size of the generated location reference, because AGORA-C uses less points for referencing a location.

The AGORA-C encoding rules provide the semantics for creating the location reference and interpreting it in the decoder. An AGORA-C location reference consists of the core profile, which describes the location itself, and the extension profile. The extension profile is optional and describes additional geometry with the aim to get a geometry pattern of roads which is sufficiently unique, so that it can be re-identified in another road map.

An extension profile is intended to be used for so-called destination locations, where the location describes a destination for a route guidance application. Especially in a case like that, a robust location referencing method is important. Using the extension profile considerably enhances the robustness of the method, because the extension profile enables the handling of locations from which roads are not present in the decoder's road map.
Intersection point: Intersection points represent intersections. They are selected on the referenced location where the road section signature changes. The road section signature consists of the attributes functional road class (FC), form of way (FW), road descriptor (RD), and driving direction (DD). To define the first segment of the location, the first location point is always an intersection point, even if it is not located on an intersection.

Fig. 5 illustrates an example of the described process.

Fig. 5A. In window (a) a location is chosen.

Fig. 5B. Window (b) in the middle shows the resulting tree. The point SP indicates the chosen starting point of the tree. The two points 00 and 01 determine the position of the location.

Fig. 5C. All the other points belonging to the tree give an indication of the surrounding network such that the correct location can be identified as shown in window (c).

Trigger for the use of the extension profile is the absence of road sections with a sufficiently high functional road class within the location in the road map of the encoder. In this case the extension part has the task to connect the location with a road of sufficiently high road class. Including a road of higher class in the location reference is motivated by the assumption that it is more probable that roads of higher class exist both in the encoder and in the decoder road map. This leads to another aim of using the extension profile. By storing the road shape of a path from a road of sufficiently high class to the location of interest it ensures that the receiving navigation system could find a connection between its own road network to the encoded location, even if this connecting path does not exist in the road map.

Two kinds of AGORA-C points are to be distinguished: core points for the core profile and extension points for the extension profile. Every point is a pair of WGS 84 co-ordinates in 10 micro degrees resolution. Core points can have one or more of the following types:

- Location point: Any point that is part of the real world location.

- Routing point: Routing points are used for reconstructing the location by route calculation. The referenced location lies on the shortest path between the routing points.

Figure 4 illustrates an AGORA-C location reference as specified in [2]. The marked location to be encoded lies between the two location points P1 and P3, the points P1, P2, P3 constitute intersection points. The attributes stored for point P1, for example, mean that the name of the referenced road contains the string “SMOLE,” the road is of class 3, and the form of way value 3 means that it is a single carriageway. NIT stands for number of intermediate intersections and means that in this case there lies one intersection between the start and the end of the location. Points P1 and P4 are the routing points, each of these points stores the distance to the next routing point in direction of the location. The extension points P5 and P6 are optional and mark an additional

The specification is still under development, which means that the here-described AGORA-C location reference can change to some extent.
geometry that in this case should help to simplify the search for the location since a short straight line like the example location shows no unique characteristic that can be recognised within a road map.

Compared to TMC, a major advantage of AGORA-C is that an AGORA-C location reference holds enough information about the road geometry and the necessary road attributes in order to import new road data into the car navigation system. We can assume that the referenced location was connected in the encoder road map, however we cannot act on the assumption that the location is also connected in the decoder road map. We pointed out the possibility that roads from the encoder road map can be missing in the decoder road map or the other way around. So, decoding the location reference requires the ability to recognise missing roads and compensate for these gaps by using the data provided by the location reference.

Although the AGORA-C specification strictly defines the behaviour of encoding a location reference, nothing is specified about the decoding procedure. Knowledge about the encoding rules is necessary for decoding a location reference, but the decoder in the car navigation system is free to choose whatever information it needs from the location reference.

Tests of AGORA-C in late 2004 [4] showed hit rates of around 98%. As specified for the location referencing projects, the hit-rate is defined as the number of successfully decoded location references divided by the total number of tested location references. Successfully decoding means that either the location was fully located in the road map of the decoder or the location or parts of it were identified not to be present in the road map.

Encoding and decoding of the test locations were carried out using digital road maps from the same vendor but from different versions and using digital road maps from different vendors. A set of 100 test locations was extracted from the area of Hannover, Germany, another set of 1000 was randomly selected within The Netherlands. The Dutch locations consisted each of a set of one to five connected edges forming a path in the road network. For short locations like these, the average code size was 37.1 bytes, the average number of points used in the location reference was 2.8.

In order to compare the reliability of AGORA-C and TMC location referencing, another test set processed 45 locations on a Dutch motorway constituting TMC locations with an extent of 7. Even with digital road maps of different vendors as data source, the hit-rate was 100% with each message size below 50 bytes, showing that AGORA-C is a very promising method.

Since 2004 the German Mobile.Info Consortium works on the development of the so-called TPEG Automotive protocol. TPEG has been developed by the Transport Protocol Experts Group since 1998 and is a protocol for Traffic and Traveller Information (TTI) providing applications, services, and transport features on wide-band bearers.

TPEG Automotive extends elements from the TPEG protocol in order to use it for broadcasting traffic messages.

For location referencing it will use TMC in case that a TMC-code exists for the location, otherwise AGORA-C will be used. The start of the practical usage of the TPEG Automotive protocol is planned for 2008 [4].

METHOD FOR IDENTIFYING LOCATIONS IN ROAD NETWORKS (MEI-LIN)

We are currently also investigating another location referencing technique [11]. On the one hand, this method also aims at decreasing the message size, but in addition to that puts a special emphasis on a better identification of the surrounding road network of the location in order to identify correct lanes.

Using this method, one special point is chosen which is either in or close to the location to be referenced. If required, more points can be chosen. However, the number should be strictly limited due to the limitations regarding the message size. Rooted at this point, a tree is built up in the surrounding road network following certain rules. The vertices of the tree are points on connected roads which have a certain driving distance from the root.

The structure of the tree can be easily coded and transmitted together with the root co-ordinate. This root coordinate is the only directly usable spatial information to be placed into the road map of the receiving system. Geometrical information like the angle of the road segment for each vertex or road attributes may be added to increase the hit-rate of the matching and to determine the exact position of the location in the tree.

In the receiving system, the co-ordinate is placed into its own digital road map. Within a certain search area around that co-ordinate potential root points of the map are chosen. Then, the same algorithm as on the encoder side is used to build up a tree rooted at each of the chosen points in order to identify its correct position. After that, the resulting trees are matched with the transmitted information of the tree from the encoder side. It is also possible to compute matching values while the tree is built up in order to discard non-matching branches before they are entirely stored. Using the geometric information, the location is identified in the tree with the best match.

If a longer location needs to be encoded, we might have to split the location and use a few small trees to reference the location. In addition to that, the method could as well be used just to reference certain important points within a location or in the road network.

CONCLUSIONS

Since 1997, real-time traffic information is broadcasted in European and American countries using TMC messages. Experiences with TMC pointed out that up-to-date traffic information is a powerful tool for regulating traffic flow. Particularly due to the low bandwidth needed for transmitting the TMC traffic messages, TMC is expected to stay in use for at least another 10 years [4]. However, concerning the
coverage of the road network, TMC has reached its limits. A
more flexible system is needed that is not bounded to
pre-coded locations and, hence, able to address the whole
road network.

Especially in urban regions, extensive traffic management
is necessary to control the traffic and provide global
strategies, e.g., parking guidance systems or traffic calming
actions, in order to reduce the traffic density and toxic
discharge. The development of AGORA-C location
references was a big step forward to improve traffic
messaging. With on-the-fly location referencing every road
section can be addressed. Location referencing works
independently from the digital road map used for encoding
the location reference in the traffic information centre and the
car navigation system is able to identify the location also
independently from the digital road map used for decoding
the location reference.

Current work concentrates on improvements of the
AGORA-C specification in order to develop an
internationally applicable location referencing method which
then becomes an ISO-standard. Positive results were
achieved with the reduction of the message size. However,
reliable methods for decoding the location references are still
not found. Car navigation systems have limited computation
power and storage space. As a consequence, a usable decoder
implementation for an on-the-fly location referencing
supporting navigation system needs to be able to decode
location references within a short time using highly limited
system resources. Besides decoding, the navigation system
has to be able to execute other computation power
consuming tasks, e.g., route calculation. Hence, research
aiming at the optimisation of the decoding procedure is going
on extensively.

The current development regarding MEI-LIN concentrates
on an analysis about the best choice for parameters like the
position of the root point or the distances of the points in the
tree. First tests already show very good results only needing a
very limited data size. Especially in complex intersections,
the method seems to be quite reliable. Extensive tests are
planned in order to evaluate whether this technique might
bring a serious improvement to methods concerned with
location referencing.

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CWLFM Radar
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ABSTRACT

Continuous Wave Lineal Frequency Modulated (CWLFM) radar presents some interesting advantages for coast surveillance and control as well as low probability of interception (LPI). In this paper we present real results obtained with a radar prototype and processed with ISAR techniques. Also, results of an automatic ship identification system applied to simulated ISAR images are exposed. Moreover, radar behavior with unfavorable meteorological conditions is discussed.

INTRODUCTION

The CWLFM radars were described long ago [1], however new technologies (HBTs, HEMTs) allow more power in transmission and low noise in reception in the millimeter band. Working at higher frequencies allows the use of wider bandwidths, improving the range resolution, and thus, the information about the targets presence, location and identity.

The CWLFM radars offer some advantages in comparison to other radar signals. First, these systems do not present "blind spot" limitations, because simultaneous transmission and reception exist but not in a dead time like in the pulse radar. Second, for the same transmitted bandwidth uses a lower sample frequency. Finally, they have good Low Probability of Interception (LPI) characteristics, due to lower peak power transmitted signal. On the other hand, CWLFM radars are simpler and their costs are lower than pulse radar with equivalent features. Other linear FMCW radar systems have also been used for coastal surveillance [2], but it is not possible to obtain high resolution ISAR images for identification due to its range resolution.

Control and coast surveillance is indispensable in the Canary Islands owed to the maritime traffic has to be identified and tracked. In this class of application, where not only detection is necessary but also target identification, optics and infrared sensors are frequently used. The drawbacks of optical systems are fog and haze (a usual atmospheric condition in the Canary Islands). In these cases the range of these systems is nearly null. The CWLFM radar range with those unfavorable meteorological conditions is obviously worse than in normal ones but the system keeps operative. In this paper, some measurements of the power losses will be exposed.

To obtain the moving ships images with respect to the static radar, ISAR processing is necessary, thus making it possible to see the real ship image [3]. This image can be processed for parameters extraction allowing automatic identification of the kind of ship as an aid to the radar operator. Simulations with twenty ships have been carried out. With the aid of Neural Networks [4], the automatic detection of ships is feasible. In this paper the results of this research will be presented.

The homodyne CWLFM radar has been developed as a project supported by the Science and Technology Spanish...
Ministry (TIC-2002-04569-C02, TEC2004-09615-C03, TEC2005-08377-C03 y TEC-2005-07010-C02). This radar transmits in the 28-30 GHz band, with a bandwidth of 2 GHz, which give a 0.075 m resolution.

**CWLFM HOMODYNE RADAR IN MILLIMETER BAND**

CWLFM systems utilize an active correlation process that consists in mixing the signal echoes with a replica of the transmitted signal, followed by a bank of filters. Mixing the received signal with the replica, distance information is converted to frequency domain, in such a way that each filter is equivalent to a distance cell. Figure 1 shows the homodyne CWLFM radar prototype developed [5]. This prototype is a radar environments data capture system, with short medium range coverage (15 Km), low price, and portable. In order to implement it, 1 GHz bandwidth VCO of 14.5 GHz is used. VCO output is multiplied by 2, to achieve a 2 GHz bandwidth. Once it is amplified, the signal is transmitted and when it finds a target, it is captured by the receiver antenna. The received signal is mixed with the coupled signal obtaining so the IF signal is filtered and amplified. The resulting IF signal is subsequently captured by a data acquisition card (GageScope) located in a PC. The digitalized signal is Doppler processed in order to obtain moving target images.

Different operating modes are possible depending on the VCO sweeping. In this way, radar BW can vary itself between 50 MHz and 2 GHz, that is, between a 3 m and 7.5 cm resolution. The radar system parameters are: 25dBm transmit power, 3° antenna beamwidth, 6 dB system noise figure, 40 MHz receiver bandwidth and 8192 range cells.

**Fig. 1A. Photographs of the RF circuitry during its testing;**
**Fig. 1B. the mechanical parts; and**
**Fig. 1C. Linear FMCW radar block diagram**

**Fig. 2. Photos and Doppler image of 3 types of vessels;**
**Fig. 2A. sailing boat; Fig. 2B. ferry, Fig. 2C. zodiac**
RESULTS

For radar security applications, images as real as possible are necessary in order to achieve the ship identification. In this line, the radar prototype presented in this paper permits us to obtain images with a resolution up to 7.5 cm, and after a Doppler processor, images in movement can be clearly identified without clutter problem. The images of Figure 2 have been obtained with the radar working just as was explained in the previous section. In the X axis the Doppler frequency (cross range) is represented, while in Y axis the distance in meters is represented.

These images show the photos of different types of ships and their Doppler images obtained through Doppler processing. The ISAR images are only FFT processed, no post-processing has been employed. Non-expert personnel can easily appreciate differences between the different ships Doppler images, doing feasible its classification.

The Doppler images of the ships are easily recognizable and if they are processed and parameterized just as explained in next section, they allow obtaining high percentages of automatic recognition.

TARGET MODELING

From a suitable set of Doppler images of each ship as the ones shown in the previous section is possible to train a recognition system (Figure 3) that makes possible automatic ship detection and classification. This system is suitable to carry out maritime traffic control.

There are many difficulties for ship identification. The ISAR image of the same ship could be different depending on ship's motion: pitch, roll, and yaw. Ship's image projection plane is constantly changing with the sea state. Another problem appears when the radar is in sea level and the ship changes the position angle with respect to the radar.

At the same time that the radar hardware was developed, several simulations have been carried out in order to see how feasible the automatic recognition is. Six different types of ships with similar size and shape were used to create a system capable of automatically classifying the type of ship from the Doppler image of the ship.

First, the reflectors of six similar ships are by hand made, as shown in Figure 4. In addition, from each of these six images, six rotations are created at 30°, 60°, 90°, 120°, 150°, and 180°. This process is repeated 20 times, but randomly varying the angle ±15° for each of the angles. In this way a database with 6 ships and 20 samples of each different angle is obtained. Each of these 20 samples is considered itself with a different angle.

Once reflectors for each of the six ships are simulated, the ISAR image for each is obtained (Figure 5), keeping in mind the yaw movement of the ship. In this way, a suitable database has been created to train the identification system.

For parameterization, the ISAR image is previously divided into three parts. For each part, a maximum, where significant elements are located, is obtained for ship recognition. With the position and the value of those three maximums a vector is obtained. Other parameters that are also used are the number of medium points contained in the image, the length and thickness of the Doppler image, and typical deviation (std) and difference in the main maximum.

Using a feedforward, perceptron, and backpropagation Neural Network, the mean recognition obtained was 98.67% with a standard deviation of 0.6 and mean false alarm rate of 2%.

RADAR BEHAVIOUR IN FOG CONDITIONS

One of the fundamental aspects in surveillance radar is the need for continuous operation: it must be operative during day or night and under any atmospheric conditions.

At the radar operating frequencies, between 28 and 30 GHz, the propagation through the atmosphere is affected by effect of the oxygen and water vapor molecules. Nevertheless, the radar prototype presents significant advantages over the lower frequencies or optical surveillance systems. That arises from the fact that they are stronger

Fig. 3: Ships identification system scheme
against the hydrometeors since the optic surveillance systems are not useful in presence of rain or fog.

In Figure 6, several photos of the same mountain, obtained with a photograph camera, one in a clear day and the other in a raining day are shown. It can be observed that in Figure 6B, the more distant mountain cannot be seen as a consequence of the rain.

In Figure 6C the radar intermediate frequency signals corresponding to Figure 6A and Figure 6B optical images are shown. The black signal corresponds to the clear day photo and the grey signal with the raining day. It can be observed that at 15 Km. the power loss due to rain is 1.5 dB (0.1 dB/km), but that continues being enough to detect the mountain without information loss.

In Figure 7 it can be verified how in case of fog, when optical images taken with the camera of high-quality video are not useful, radar images keep working without problem and without information loss. Therefore, high resolution CWFM radars are less affected by fog, and present some advantages over optical surveillance systems in these conditions.

CONCLUSIONS

High resolution FMCW radar has been presented for surveillance applications such as ship detection and recognition. In addition, concrete measures and results have been exposed in order to illustrate system behavior. Also automatic recognition possibilities have been discussed. It has been shown that this type of radar has some advantages in surveillance systems in presence of fog due to being less sensitive to the weather factors than optical systems.

FUTURE WORK

At the moment we are creating a database with real Doppler images of ships captured by the radar. With this database, real ship automatic identification could be developed. The difficult part is to obtain the necessary amount of images of each ship in order to train the recognition system. Another problem is that in real conditions, ships have different velocities and that
causes the ISAR image to be different for each ship velocity, making automatic ship identification more complex.

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Coordinated Continual Planning Methods for Cooperating Rovers

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ABSTRACT

Eight evaluation metrics are used to compare and contrast three coordination schemes for a system that continuously plans to control collections of rovers (or spacecraft) using collective mission goals instead of goals or command sequences for each spacecraft. These schemes use a central coordinator to either: 1) micromanage rovers one activity at a time; 2) assign mission goals to rovers; or 3) arbitrate mission goal auctions among rovers. A self-commanding collection of rovers would autonomously coordinate itself to satisfy high-level science and engineering goals in a changing partially understood environment – making the operation of tens or even a hundred spacecraft feasible.

INTRODUCTION

While explicitly commanding a spacecraft via low level command sequences has worked spectacularly on previous NASA missions, there are limitations deriving from communications restrictions – scheduling time to communicate with a particular spacecraft involves competing with other projects due to the limited number of deep space network antennae. This implies that a spacecraft can spend a long time just waiting whenever a command sequence fails. This is one reason why the New Millennium program has an objective to migrate parts of mission control tasks onboard a spacecraft to reduce wait-time by making spacecraft more robust [1].

In general, autonomous platforms (rovers or spacecraft), must balance long-term and short-term considerations. They must perform purposeful activities that ensure long-term science and engineering goals are achieved and ensure that they each maintain positive resource margins. This requires planning in advance to avoid a series of short-sighted decisions that can lead to failure. However, they must also respond in a timely fashion to a dynamic and partially understood environment. In terms of high-level, goal-oriented activity, the platforms must modify their collective plans in the event of fortuitous events such as detecting scientific opportunities like a sub-storm onset in Earth’s magnetosphere or a Martian hydrothermal vent, and setbacks such as a spacecraft losing attitude control. For an autonomous spacecraft, the software to satisfy these requirements can be partitioned into four components corresponding to a belief-desire-intention (BDI) architecture [2]:

- a mission manager to generate desires by computing the high level science goals from commands and detected opportunities,
- a planner/scheduler to generate intentions by turning goals into activities while reasoning about future expected situations,
- an executive/diagnostician to generate beliefs by interpreting sensed events while initiating and maintaining activities, and
- a reactive controller to execute actions by interfacing with the spacecraft to implement an activity’s primitive feedback loops.

Whether they are orbiters, probes or rovers, coordinating multiple distributed BDI agents introduces unique challenges for all four autonomy-supporting technologies. Issues arise concerning interfaces between agents, communication bandwidth, group command and control, and onboard capabilities. For example, consider a mission with a cluster of satellites simultaneously observing a point on a planet from different angles with different sensors. Each will only have a finite amount of communication bandwidth, limiting the amount of information that can be shared between the satellites (and a ground station). The onboard capabilities also need consideration, including computing power and onboard data storage capacity. This will limit the level of autonomy each satellite can have. Finally, these issues apply to multiple rover missions, too. A group of rovers might want to simultaneously measure vibrations caused by an explosion to determine the subsurface geology of an area on Mars.

This paper compares and contrasts three ways to distribute a planner/scheduler amongst a population of rovers that have separate executive/diagnosticians and reactive controllers.
The first approach places the planner/scheduler on a lander that remotely commands the rovers. The second is more distributed in that it replicates a planner across the population to let each rover plan its own activities, while the lander handles goal distribution. The last approach advertises all goals and lets each rover bid for a goal based on how well its local planner can satisfy the goal given local information. These approaches delineate a space of approaches where the platform that distributes tasks maintains progressively less information on the entire population.

This paper’s sections subsequently describe thought experiments for multi-rover missions that motivate eight performance metrics for evaluating approaches toward continuous task-distribution-based coordination, explain how continual planning lets a population adapt to local conditions, compare and contrast three coordination methods, discuss related work, and finally conclude.

**MULTI-PLATFORM THOUGHT EXPERIMENTS**

In order to focus this discussion on distributed autonomy in space, consider different types of observations that motivate future multi-rover missions. There are four such kinds of observations depending on the phenomena being measured:

- improved coverage when observing/exploring large areas (like a number of identical small rovers for exploring a remote area);
- specialized probes with explicitly separate science objectives (like a fast scout rover followed by a slower rover with more sensors);
- multi-point in-situ sensing for observing large scale phenomena that are only detectable with multiple spatially separated in-situ sensors (like a number of rovers determining chemical gradients within the Martian atmosphere); and
- building large synthetic aperture sensors with many small spatially separated sensors (like a number of rovers observing near-surface stratigraphy by making seismic tomography measurements).

These reasons for having multiple platforms in a mission are not exclusive. For instance, a rover might alternate between observing rocks in isolation and participating in a seismic tomography measurement.

**Coordinating Task Distribution**

In missions where each rover performs its task in isolation, the difference between an autonomous multi-rover mission and many autonomous single rover missions involves distributing tasks to the different rovers. While the task distribution for multiple autonomous single rover missions is determined on the ground, an autonomous multi-rover mission can distribute and redistribute tasks remotely. This feature improves both distribution quality and robustness by letting the population use local information to optimize the initial task distribution and to redistribute tasks when a rover suffers an anomaly, unexpectedly finishes a task early, or detects an unanticipated science opportunity.

As an example of coordinated autonomous task distribution, consider multiple rovers surveying rocks in an area on Mars using MISUS [3]. In this system a Mars lander manages a population of rovers by analyzing data from past observations, determining new observations, assigning observation goals to rovers, and collecting data as each rover moves from rock to rock, performs experiments in isolation, and analyzes its local observations (Figure 1). This system autonomously maximizes science return while balancing the load among the rover’s.

![Coordinating rovers with MISUS](image)

**Fig. 1. Coordinating rovers with MISUS**

**Coordinating Task Execution**

The multi-point in-situ sensing and large synthetic aperture tasks differ operationally from the other two classes in that the separate rovers do not operate in isolation. For instance consider a seismic tomography measurement. To determine near-surface stratigraphy, one rover detonates an explosive charge while others measure vibrations at remote areas. By knowing the relative locations of the rovers and comparing the measured vibrations, we can determine the composition of minerals near the surface beneath the rovers. To make these measurements, the rovers must tightly coordinate their activities to assure that each rover is both correctly positioned and measuring vibration when the explosion occurs.

Coordinated task execution is easier than coordinated task distribution. For smaller missions designating a master rover that commands the other (slave) rovers as though they were physically attached solves this problem, but bandwidth restrictions keep this approach from scaling with either the number of slaves or the complexity of each slave. Resolving this scaling issue is outside the focus of this paper.

**Autonomy Architectures**

In an earlier paper [4] we describe three different autonomy architectures for a constellation of spacecraft
involving leaders, followers, and slaves. Here we expand this taxonomy to also include contractors. The number of autonomy modules on a spacecraft determines which of the four classes it falls into:

- a slave has no modules and is tele-operated by the reactive control module of another nearby spacecraft;
- a follower has both an executive/diagnostician and a reactive controller (like many existing spacecraft);
- a contractor has a follower’s components and a planner/scheduler to optimize local activities (like DSI’s remote agent experiment); and
- a leader has a contractor’s components with a mission manager to determine and distribute new goals.

With these four classes, we can define a multi-platform mission’s autonomy architecture by stating the class of each platform, and how the collection of platforms coordinates its activity. In terms of MISUS, the architecture consists of having the leader lead, and letting the rovers act as followers or contractors depending on the desired local autonomy.

Performance Metrics

Given a multi-rover mission, there are two sets of metrics for evaluating the acceptability of autonomy software. The first set motivates minimizing the amount of remote autonomy and has 4 metrics:

- 1. the amount of explicit control an operator has over the population’s activities,
- 2. the feasible accuracy of modeling the population’s activities on the ground,
- 3. the autonomy software’s testability, and
- 4. the amount of needed onboard computing power.

While the first set of metrics tend to be maximized by reducing the amount of autonomy on a constellation, the second set of four evaluation metrics are maximized by increasing remote autonomy:

- 5. the population’s event response time,
- 6. the required bandwidth between platforms and Earth,
- 7. the quality of the downlinked data, and
- 8. the functional redundancy.

CONTINUAL PLANNING

Both single and multiple autonomous rovers must respond to a (somewhat) dynamic, unpredictable environment. In terms of high-level, goal-oriented activity, a planner needs to modify rover sequences to account for fortuitous events such as observations completing early and setbacks such as a failure to traverse an assigned path.

The need to rapidly respond to unexpected events motivates continual planning, an approach where a planner continuously updates a sequence in light of changing operating context. In such an operations mode, a planner would accept and respond to activity and state updates on a one to ten second time scale. CASPER [5] is an example of a continual planner based on a heuristic iterative repair approach toward planning [6, 7]. This approach takes a complete plan at some level of abstraction and manipulates its actions to repair detected flaws. Example flaws would involve an action being too abstract to execute or many simultaneous actions with conflicting resource needs.

Making a heuristic iterative repair planner continual within a planner/scheduler module results in Figure 2’s algorithm. The first line assures that the PROJECTION variable always reflects how the state of a rover should evolve as its plan executes, and the fifth line causes this execution by passing near-term activities to the executive/diagnostician. Upon passing a near-term activity, a rover is committed to its execution and the planner can no longer change it – only the executive/diagnostician can. These near-term activities are defined as those that start within a domain specific amount of time in the future, and the time between now and that future point is the planner’s commit window.

The expected future state evolution changes as a plan gets new goal activities and the perceived state diverges from expectations. This divergence is caused by unexpected exogenous events and activities having unexpected
outcomes. Since a planning model can only approximate the reality experienced during execution, there is no way to guarantee the impossibility of unexpected state changes in nontrivial domains.

At any moment the projection can detect flaws in a local plan, and lines 2 through 4 select and apply repair methods to fix the flaws that appear after the commit window. For instance, a rover’s observation activity can take an unexpectedly long time to complete. Depending on the delay, a subsequent observation may be impossible due to sunset occurring before the rover can reach the appropriate measurement location. A repair method might fix the flaw by rescheduling the observation to a later time, like the next morning.

Those flaws that involve committed, or executing, activities are repaired using domain specific techniques within the executive/diagnostician. Using a commit window to determine whether or not the planner/scheduler fixes a flaw is motivated by the computational cost of planning and scheduling. When a flaw appears in the commit window, a fast correct technique is needed to fix the problem, like just deleting all offensive activities. When the flaw appears after the commit window, there is time to alter the plan with slower techniques that produce more optimal results. While enlarging the commit window guarantees the planner more time to fix problems with actions outside the window, it also increases the executive’s complexity for handling problems with larger numbers of committed activities.

COORDINATING MULTIPLE ROVERS

In an earlier paper [8], we compared three methods for coordinating a population of rovers from a central lander in the MISUS scenario described in Multi-Platform Thought Experiments. The first and simplest method involved using a central planning to manage a population with a leader-follower architecture, where the lander generates plans subsequently executed by the rovers. The second method involved distributed planning where each rover planned its own activities, and the lander planned for all rovers at an abstract level to determine how to distribute goals amongst the rover population. Finally, the third method pushed all planning onto the rovers and left an auctioneer on the lander to distribute goals based on a contract network protocol [9, 10] – a commonly used coordination paradigm within the distributed artificial intelligence community. Within a contract net protocol, an auctioneer announces a task to a set of contractors, each contractor bids for it, and the auctioneer awards the task to the contractor with the best bid.

Within these three methods there was an underlying assumption that the population operated a static well-understood environment. The system planned all activities, executed them, and then planned for the next set of activities. There was little thought about what happened when the environment became dynamic and partially understood – the motivations for continual planning.

Central Planning

The simplest way to extend continual planning for single-rover autonomy to autonomous multi-rover missions involves using a master/slave approach where a single leader performs all autonomy reasoning. The slaves only transmit sensor values to the leader and forward control signals received from the leader’s reactive controller to their appropriate local devices. In this way the entire system is treated as a single multi-armed lander.

Altering this system by closing reaction loops on board the slaves to reduce the massive communication requirements results in a leader/follower approach (Figure 3), where a lander uses a central planner to manage three rovers. Within the planner box, planned activities are represented as horizontal bars with effects on resources appearing below. While the planner can move some of these activities, others are fixed to represent exogenous events like sunset. The commit window overlaps the planner box and moves to the right over time. Whenever the window moves over a primitive activity, the activity is committed and sent to the appropriate executive/diagnostician. As a rover performs activities, it observes local conditions and sends state updates back to the lander to facilitate projection revision.

With respect to our eight evaluation metrics, using a continual planner with a master/slave approach toward multi-platform coordination facilitates allowing a variable amount of remote autonomy. At the least autonomous extreme the continuous planner is given low-level command sequences and can only apply a go-to-safe-mode repair method upon detecting a flaw. This extreme maximizes the first set of metrics. The most autonomous extreme reduces the first set of metrics while improving the second set. Here the planner is only given a set of abstract activities and uses local information and heuristics to improve event response time and the quality of downlinked data. While functional redundancy and inter-platform bandwidth are unaffected by
moving from one extreme to another, turning the slaves into followers increases redundancy and reduces bandwidth. Due to how easily this change can degrade the event response time, turning slaves into followers is an active research topic in the multi-agent research community [11].

encoding one of these approaches into our distribution planner, the lander can both determine how to distribute the goal activities and provide a rough estimate on the order in which a rover should visit its targets to perform the goal activities.

With respect to our evaluation metrics, distributed planning facilitates variable autonomy both with the ground and across the platforms. Minimizing autonomy across platforms involves making the distribution planner use full information and generate low-level action sequences for the other platforms, which can only execute their actions. This restriction turns distributed planning into the previously evaluated central planning approach.

Maximizing autonomy on the contractor platforms has the same effects as maximizing autonomy for the central planner, but also adds a reduction to inter-platform bandwidth needs. The lead platform no longer needs to maintain full state information, and each platform’s planner can locally respond to events without informing the leader. Now a contractor can resolve a flaw by either quietly shuffling its local activities or reporting failure to the leader upon deleting a local activity. This quiet shuffle reduces bandwidth needs while failure reporting facilitates moving activities between platforms via the leader’s continuously repairing its goal distribution plan.

**Contract Networks**

One way to minimize the amount of continuously updated rover information on the lander results in taking a contract network approach toward coordinating multiple planners (Figure 5). Here a leader advertises each goal and each contractor bids on the goals based on its local information. To respond to an unexpected event, a contractor will either quietly shuffle its activities or delete a local activity and report failure to the leader. Upon hearing of a failure, the leader can re-advertise the failed goal for auction. Notice that there is no need for continuously updated partial contractor information – the leader does not need to know anything about the contractors to auction a goal.

Using a contract net protocol to implement a greedy solution to the MTSP involves making the lander take goal activities and incrementally advertise them to all rovers. Upon receiving a task, a rover uses its onboard planner to try to fit a solution to the goal activity into its current schedule. Upon succeeding, a rover bids its total projected travel distance after including the new observation. Rovers that fail to insert the task within a time limit do not participate in the auction. While receiving bids, the lander keeps the best bid and continually rejects lesser bids. When the auction’s time limit is reached, the lander awards the task to the rover with the best bid. By bidding the total distance the rovers minimize the maximum rover travel distance – an MTSP solution. This use of a rover’s continual planner to bid exposes another tradeoff involving the length of each rover’s commitment window. While a longer commitment window results in allowing longer auctions with more participating rovers, a shorter commitment window keeps each rover from having to use the fast sub-optimal plan repair techniques.
Goal Auction

Failed Goals

Single goal for auction

Bid acceptance or rejection

Bid for goal

Executive

Fig. 5. Continual goal auction

With respect to our evaluation metrics, letting an operator restrict the platforms that can bid for certain activities results in a system with variable autonomy. At one extreme the operator can specify a low-level activity sequence for each platform, and at the other the leader gets a set of high-level goals that can go to any platform.

As before, the first extreme scores best on the autonomy minimization metrics, and the second scores best on the autonomy maximization metrics. While this approach has lower inter-platform bandwidth needs than the other approaches, it has more computational overhead and assumes a greedy approach toward optimization.

RELATED WORK

While there is a large literature on cooperating robots, most focuses on behavioral approaches that do not explicitly reason about partitioning goals and planning courses of action. Three notable exceptions are GRAMMPS [13], MARS [14], and RETSINA [15]. GRAMMPS is a system coordinating multiple mobile robots visiting locations in cluttered, partially-known environments. This system shares quite a bit of similarity with our central goal allocation with distributed planning architecture for rovers. Both systems solve an MTSP problem to distribute targets, and both have low-level planners on each mobile robot, but GRAMMPS focuses on path planning while learning a terrain instead of focusing on resources and exogenous events. On the other hand, MARS is a cooperative transportation scheduling system that shares many similarities with the contract net approach, and RETSINA uses peer-to-peer coordination similar to goal distribution planning. Neither MARS nor RETSINA model known exogenous events or provide default mechanisms for altering plans and transferring goals to resolve execution failures.

Other systems applying cooperating robotics research in aerospace domains include TeamAgent™ [16] and an architecture for autonomy developed at LAAS-CNRS [17]. While the TeamAgent™ taxonomy of agents participating in a population has many similarities to our slave, follower, contractor, and leader breakdown, this system focuses on a behavioral approach. The system from LAAS-CNRS on the other hand shares many similarities with our continual goal distribution planning approach. This system managed a fleet of 30 mobile robots that transported containers inside a building.

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CONCLUSIONS

This paper compared and contrasted three continuous task-distribution-based coordination schemes for commanding multiple rovers with collective goals instead of goals or command sequences for each rover: central planning, distributed planning, and contract networks. All schemes supported variable autonomy and were evaluated with respect to eight different metrics. At the lowest autonomy setting, all schemes devolved into commanding the platforms with low-level sequences, and at the highest autonomy setting the schemes differed primarily in terms of needed onboard computing, inter-platform bandwidth, and redundancy. Figure 6 summarizes the effects of increasing autonomy on the metrics. The circled points for the central control scheme reflect that autonomy did not improve bandwidth or functional redundancy. This is due to the fact that rover to lander crosslinks dominate bandwidth needs, and only having one planner controlling the entire system limits functional redundancy. The circled point under distributed planning arises from the fact that the distribution planner needs to be tested in addition to testing the rovers' low-level planners. Finally, the circled points in the contract
network column reflect the fact that having each rover plan and make bids for all goals. While this implies an increased computing need on each rover, pushing the computation onto the rovers increases redundancy since the simplicity of arbitrating an auction implies that any rover can arbitrate when the lander cannot.

Reasoning about incremental autonomy for distributed planning and contract networks results in a realization that these approaches toward coordinating multiple planner/schedulers can be combined. The resultant approach would use a goal distribution planner, but would only collect enough information to limit the number of platforms that participate in an auction. One avenue for future work involves building a coordination mechanism that spans the space between contract networks and distributed planning. Another future research direction involves generating joint activities for multiple spacecraft/rovers to collectively satisfy. This would extend our approach to coordinating task execution for multiple platforms. Finally, a third research direction involves making the rovers/orbiters compete for shared resources, like communications opportunities.

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Selective Combinations in Personal Satellite Navigation

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ABSTRACT

Methods for selecting satellite combinations in personal satellite navigation are presented and categorized. The methods include different algorithms and various data parameters and computed parameters. This paper offers a summary on the topic as well as future considerations.

INTRODUCTION

In personal satellite navigation, the diversity of operating environments sets challenging tasks for Global Navigation Satellite System (GNSS) receivers. Personal satellite navigation means navigation performed by an individual, thus marine and aviation navigation are excluded from the topic. Personal navigation can be set out in any environment, and therefore, all the details on the actual operating environment are not known in advance, but a few assumptions can be made. The operating environment is often characterized by the challenges of urban environment and those caused by limited resources of the personal positioning devices.

Choosing a selective combination or is one of the challenging tasks of GNSS receivers. In this task, the satellite signal set producing the most accurate position is determined and, possibly, the accuracy of positioning with this chosen set is defined. Selective combining is a new term, introduced by the authors to separate the task from signal selection related to signal acquisition, which is a base band signal processing task. The problem of selective combining is closely related to integrity monitoring (IM), which refers to the receiver’s ability to produce timely warnings about the reliability of the system [1].

The word “integrity” has a strong contextual reference to aviation navigation. Requirements of accuracy, integrity, and continuity of service for the GPS receivers that are used in aircrafts have been directing the development of the receivers, also the development of integrity monitoring methods. In personal positioning, emergency positioning requirements are set by a mandate E911 in the United States and a respective regulation E112 in the European Union.

Integrity of positioning can be separated from quality of positioning. Integrity refers to a phenomenon that can be observed but not greatly affected. The space and the control segments in GNSS positioning are beyond users’ influence. Users can only observe that signals of particular integrity are available for positioning at a specific time instant. Quality, in turn, is related to the receiver’s performance under the prevailing circumstances. Thus, quality of positioning can be affected by the user segment. In other words, GNSS receivers are of different quality, and these receivers observe signals from a GNSS system having a certain level of integrity.

Integrity and quality are joined when the questions are simple: “Is my position trustworthy? How accurate is it? Which satellites should I use to have the least-faulty position estimate?” At the user level, it is reasonable to disregard the source of an error when searching for an answer. As mentioned in [2], it is essential to have the IM process at the user level, since this is the only place where all information used to form the position solution is present. Therefore, there is no feedback from the IM process to the receiver to influence its performance. Instead, the position solution which has run through the integrity checks is produced as the output of the system. Figure 1 describes the problem formulation.

The decision-making process in selective combining is not a trivial task of “just choosing the best signals.” Instead, controversy is met in signal selection, and trade-offs must be made while searching for the “optimal” selection. Additionally, the more there are satellites, the more there are possible subsets. Figure 2 illustrates the increasing complexity. However, the computational power in hand-held and mobile devices has been increasing, too.
We conclude that originally, the integrity monitoring methods have been designed to identify failures of GNSS systems to warn aviation users. The objective of these fault detection methods has been to identify integrity of a GNSS system that is independent of the user, as described in [3-5]. On the other hand, the motivation for integrity monitoring in personal positioning arises from the user segment. Satellite navigation is exposed to severe signal degradations in urban environment: multipath, cross correlation phenomena, signal reflections, and signal attenuations due to constructions and foliage are common. Indoor positioning is another, yet more challenging, urban positioning platform. The signal noise levels of the received signals vary greatly in these environments, especially when high-sensitivity receivers are used. However, the enhanced sensitivity is necessary under the conditions of the described urban environment [6].

In this paper, all the methods for selecting satellite combinations in personal satellite navigation are presented and categorized. This paper is motivated to give an up-to-date survey on selective combining. The presented methods include previous work and work carried out by the authors, including mainly the KDOP method and signal condition analysis. The previous work and work by the authors are separated by the references accordingly.

**MOTIVATION FOR SELECTIVE COMBINING**

**Supporting Systems Do Not Make Selective Combining Obsolete**

Selective combining or integrity monitoring in personal positioning has not been of prime interest in the GNSS forums in recent years. This is despite the fact that personal positioning, assisted GPS, and indoor GPS – all platforms that require careful signal selection – have gained a lot of attention. While the environment-dependent performance of a stand-alone GNSS receivers is recognized, selective
combining (integrity monitoring) methods are not assumed to improve the performance of the GNSS receiver— at least not to significant extent. Instead, many other systems have been suggested to be integrated with or to support GNSS receivers to prevent the same faults that integrity monitoring tries to prevent. Such systems include different sensor systems [7], inertial measurement units, barometers, compasses, and external systems, like pseudolites [8], cellular networks [9], and wireless LAN networks [10]. However, these supporting systems do not make the task of selective combining obsolete neither vice versa. In personal positioning, GNSS remains the main positioning system, which is supported or supplemented by other systems. In the future, the implementation of intelligent selection methods in the receiver could distinguish this receiver from others, especially under difficult positioning circumstances. Table 1 summarizes the motivating aspects for selective combining in different situations as the number of visible satellites varies.

Improved Receivers Require
Careful and Intelligent Selective Combining

The current receivers for personal positioning are sensitive for tracking noisy signals, and additionally, there are "high sensitivity" receivers available in the market. Enhanced sensitivity enables the receiver to track signals with high noise levels. However, using all the visible satellites does not always result in the most accurate position [11], and on the other hand, "if the subset geometry without a failed satellite is extremely weak, positioning errors may be worse if the biased measurement is not used in forming the navigation solution" [12]. The receiver must be able to balance between the two factors affecting the positioning accuracy: signal errors and geometry of the selected subset. The satellite geometry can be degraded significantly if a satellite signal is omitted only due to its low power level.

The ability to perform such a balancing is characteristic to an intelligent selection scheme. Therefore, receivers need tools for this challenging selection task. These are analyzed in the following.

DATA IN USER-LEVEL SELECTIVE COMBINING

Different data parameters are available for the user to determine the quality of the signal. The parameters are divided into three subgroups: A) GNSS related data, which means data that is provided by the GNSS system (GPS case only); B) User related data, which means data that is dependent of and produced by the user segment; and C) Computational parameters, which require (minor) data processing.

Despite all of these data parameters, a lot of information remains unknown. Low C/No value can indicate multipath phenomenon, but this is anything but a trivial relation. One might suggest that all low-level signals are simply discarded, but this would leave us without signals in many situations. As time (to first fix) is crucial and a poor fix is better than no fix, selective combining methods cannot take too much time or be too restrictive. Therefore, even the best combination of tools cannot guarantee anything but a better on-the-average performance than without them.

GNSS Related Data (GPS case only)

User Range Accuracy (URA) is a prediction of the signal accuracy. URA index is sent in the navigation message, in
The subframe 3. In 1999, URA computation was updated which made URA a more reliable signal health indicator [13]. However, URA is only a prediction of errors for which Space and Control Segments are responsible, e.g. clock and ephemeris errors. Therefore, it does not include any user-dependent errors. URA value may vary over a given subframe fit interval, but the URA index (N) reported in the navigation message corresponds to the maximum value of URA anticipated over the fit interval [14].

Health bits are another satellite condition parameter delivered in the navigation message. The subframe 1 contains a six-bit health indicator that refers to the transmitting satellite. The most significant bit (MSB) summarizes the health of the navigation message and the five least significant bits (LSBs) indicate the health of the signal components. Additionally, the subframes 4 and 5 contain two types of signal health information, describing the health of the navigation data and of the signal components. Further details are publicly available [14].

Date of ephemeris describes the age of the ephemeris data, more precisely it tells the time from ephemeris reference epoch [14]. Ephemeris is usually updated every two hours, and it remains valid for four hours, so missing one update is not crucial. However, after four hours, if the ephemeris is not updated, the resulting error begins to increase dramatically.

User Related Data
Carrier-to-noise ratio (C/No) is usually a trustworthy parameter about the signal condition. However, personal satellite navigation environment is often quite a challenge for the receiver: indoors the signal levels are inevitably lower than outdoors. Especially, if a signal is received directly (line-of-sight) in indoors, the direct signal may be weaker than reflected signals. Thus, while indoors, carrier-to-noise ratio does not necessarily tell the “truth” about signal condition at all – the weaker signal is in fact the better signal. Therefore, reasoning about signal condition cannot be based on the mere C/No. However, it remains true that the lower the C/No, the more there are errors in the signal – even if it was “the better” signal out of a bunch of multipath-deteriorated signals.

Carrier-to-noise ratio has been used in signal weighting, i.e. giving more credit for signals with better C/No. In a similar fashion, elevation angle has been used for weighting the signals [15]. Elevation angle correlates to the length of the distance that the satellite signal has to travel through space before reaching the receiver. It is obvious that in many cases elevation angle and carrier-to-noise ratio are correlated. However, again, there are cases that break this correlation. In indoor positioning, the low-elevation signal may reach the signal through a window and higher-elevation signals have to penetrate concrete walls, thus they become more attenuated than the low-elevation signal.

Computational Parameters
Differential data observables reveal positioning faults when a sudden change in the observable occurs. Abrupt increase or decrease in the change between two time-successive measurements reveals a possible error in data processing. Differential measures take us a step closer to filtering. Kalman filtering is widely used in navigation applications, e.g., to integrate position data from two or more

<table>
<thead>
<tr>
<th>Case</th>
<th>Satellites</th>
<th>Situation</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0-3</td>
<td>Not enough satellites for positioning, unless other information available</td>
<td>Other methods required to obtain position</td>
</tr>
<tr>
<td>II</td>
<td>4</td>
<td>Just enough satellites for positioning</td>
<td>Selecting methods cannot be be employed, since signals cannot be discarded. <em>Is the obtained accuracy acceptable?</em></td>
</tr>
<tr>
<td>III</td>
<td>5-12</td>
<td>Enough satellites. FDI/FDE possible</td>
<td><em>How do we know if it is optimal to use all visible satellites?</em></td>
</tr>
<tr>
<td>IV</td>
<td>13 – . . .</td>
<td>Plurality of satellites. FDI/FDE possible</td>
<td>Same as in case III. Also: if more satellites are in view than there are channels; which signals are discarded?</td>
</tr>
</tbody>
</table>
sources. However, the filter itself needs integrity data and does not make integrity monitoring obsolete.

While everything is functioning correctly in a GNSS receiver, the difference between the previous and the current elevation or azimuth angle remains quite constant from epoch to epoch. Therefore, abrupt changes in the elevation or azimuth angles reveal errors in user or satellite position. If the change occurs in all angle values, then the error is in user position. If the change is related to only one satellite, then the error is in the respective satellite position.

The velocity of the user can be computed from the Doppler frequency. Velocity can also be derived from successive position fixes or pseudoranges. Thus, comparison of different velocity estimates can be used for error detection. In addition to this, a sudden change in velocity may also be used as an error indicator, at least when it is known that the receiver is used by a person (for example) and, therefore, there is a limit to the accelerations that may occur.

METHODS IN USER-LEVEL SELECTIVE COMBINING

A distinction should be made on selection methods before position computation and selection methods after position computation. The most distinguished methods in fact are available only after position computation. Once a fix is created, a satellite combination has obviously already been accomplished. However, many integrity monitoring methods have to first assume one combination and compute a fix before anything can be reasoned about the integrity of the selected satellites. Methods that are available before computing even the first fix include only signal condition analysis or signal condition masks.

The integrity monitoring methods affect the position estimate, since the position is possibly re-computed with a new satellite combination, excluding one or more satellites. The integrity monitoring methods can also reject the position estimate or identify it as faulty, or declare that a position estimate is not available with the current signals. In the following, the methods are divided into three subgroups: A) methods for Position Confirmation, B) RAIM Methods, C) Signal Analysis Methods, and finally D) Methods related to dilution of precision or DOP. Table 2 summarizes this section.

Position Confirmation

The first thing to do with a position estimate or a fix (especially the first fix after turning on the receiver) is to confirm that the fix is plausible, at least according to any other information that is available about our position. This first integrity check is usually done by comparing the first fix to the most recent fix available. However, the most recent fix is not necessarily close to the current location at all. It is obvious that the user may have traveled a great distance since the last time he used the receiver.

Another possibility to obtain this reference position is to contact a third party that provides a location estimate upon request. This reference position can be based on a keyword, a name of a location, or such. Yet another approach is to utilize cellular network positioning, which results in good estimates of the user location in personal positioning [16]. The cellular network consists of cells that serve phone users in a particular geographical area. Therefore, the current serving cell of the user can be associated unambiguously with a location. This reference location can be provided to the user upon request by the network operator or it can be available in the cellular unit beforehand, if a database containing cell position information has been downloaded.

RAIM Methods, Fault Detection, and Isolation/Exclusion

The best-known selective combining method is Receiver Autonomous Integrity Monitoring (RAIM) which is based on self-redundancy tests of GNSS data [1]. The term “RAIM” is sometimes used as an equivalent term to integrity monitoring, not referring to any particular integrity algorithm – only referring to the receiver’s efforts in integrity monitoring and the independence of the receiver in this task. In this paper, we use the term “RAIM” to refer especially to the fault detection algorithms which are based on self-redundancy test or tests.

Two different RAIM approaches can be named: snapshot schemes, which employ only current measurements in self-consistency checks, and filtering schemes, which use both past and present measurements. There are three types of snapshot schemes; range comparison method [17], least-squares residuals method [12], and parity method [18]. The equality of these three methods has been proved [19].

Fault detection and isolation (FDI) and fault detection and exclusion (FDE) are commonly used terms referring to a variety of different fault detection methods. Both are RAIM methods, and are, therefore, based on self-consistency checks of received data. These methods in fact compare position fixes with different sets of satellites. The difference between FDI and FDE is not necessarily clear in all contexts, but as a non-standard interpretation; FDI means search and isolation of a single error, while FDE means search and exclusion of multiple errors. Thus, FDI methods cannot recognize multiple errors. On the other hand, FDE can be used to isolate one error, too.

There are two parts in RAIM fault detection algorithms: first part is the geometry screening algorithm which determines whether the current satellite geometry allows RAIM usage. The second part is the fault detection in which the failure is searched for. The FDI and FDE methods take user and satellite positions as input and they output the suggested combination. In other words, the selected combination is based only on satellite geometry and data redundancy. In general, signal condition is not considered in RAIM algorithms, although weighted RAIM has been proposed [2].

Although RAIM methods have been introduced in the 1980s, they have been studied in recent years as well in different platforms and different variations have been proposed. Today, the role of RAIM in its original environment, aviation, is different from the original. WAAS
is the primary integrity monitoring system, and RAIM is a back-up solution in situations where WAAS is unavailable [20]. Despite its role as a back-up system, RAIM methods are continuously studied.

Evidently, GALILEO will revolutionize also the RAIM approach by doubling the number of visible satellites to a GPS/GALILEO user but simultaneously the probability of a faulty satellite is doubled as well. The combined use of GALILEO and GPS in the RAIM approach has been studied in [21] and in [22] in a WAAS context.

Availability of exclusion, or the lack of it, has been recognized as the problem of the traditional snapshot approach. Recent RAIM studies include a new improvement to RAIM availability by barometer aiding, proposed by the originators of the RAIM filtering scheme [23]. In this novel method, the measurements are weighted non-uniformly as they are in the KDOP exclusion method, too. The inventors named this method NIORAIM and propose it also for two-fault detection [24]. Detection of multiple faults is more difficult than detection of a single fault and is addressed lately also in [25] and [26]. The advent of GALILEO encourages the research on two or multiple fault detection. Aviation requirements still drive RAIM development in [27] where better availability is aimed for.
Table 2. A Summary on the Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Input Parameters</th>
<th>Output Parameters</th>
<th>Sensitivity (to detect errors)</th>
<th>Latency Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position Confirmation</td>
<td>Previous or external position information</td>
<td>Position solution to be excluded (if any)</td>
<td>Poor. Only gross errors are detected</td>
<td>Depends on the source of the reference position. If a reference position is obtained via cellular network, latency period is typically a few seconds.</td>
</tr>
<tr>
<td>FDI/FDE</td>
<td>Geometry &amp; Redundancy</td>
<td>A satellite to be excluded (if any)</td>
<td>Good. Adjustable by parameters</td>
<td>Same as the data output interval (1 s typically)</td>
</tr>
<tr>
<td>Signal Condition Analysis</td>
<td>Data Parameters</td>
<td>Satellite to be excluded (if any) and/or weighting parameters for other functions</td>
<td>Depends on the thresholds (set by user)</td>
<td>Depends on the parameter. From 1 second to 2 hours (ephemeris).</td>
</tr>
<tr>
<td>DOP-related Methods</td>
<td>Geometry</td>
<td>Position solution to be excluded (if any)</td>
<td>Depends on the thresholds (set by user)</td>
<td>Same as the data output interval (1 s typically)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>If N limited, then satellite exclusion possible</strong></td>
<td></td>
</tr>
<tr>
<td>KDOP Method</td>
<td>Geometry and signal condition estimates</td>
<td>A satellite to be excluded (if any)</td>
<td>Very good. Depends on the thresholds (set by user)</td>
<td>&quot;</td>
</tr>
<tr>
<td>Computational Parameters</td>
<td>Velocity (of the user), elevation, azimuth</td>
<td>Position solution to be excluded (if any)</td>
<td>Poor. Only gross errors are detected</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

Signal Condition Analysis

In Position Confirmation, several different data parameters were listed. These parameters can be used for signal condition analysis. This can be done using probabilistic methods by associating parameters with a probability. Probability functions describe the probability of error in signal (in meters, for instance) vs. parameter values. These functions cannot describe reality precisely, but they offer one method to analyze signal condition or signal integrity, and to create weight functions.

DOP Related Methods

The geometry of the selected satellite subset is the other of the two major factors of positioning accuracy (the other being the condition of the satellite signals) and DOP describes the “goodness” of this geometry effectively. Originally, DOP values (or predictions of it) were used for scheduling GPS data collection experiments. The relationship of DOP with the positioning accuracy has been studied extensively in previous work. GDOP was an important analysis tool to select the optimum set of four satellites [28]. The minimization of GDOP with four satellites was recognized to be (almost) equal to finding the maximum volume of a tetrahedron defined by four unit vectors directed to the selected satellites. It is proved in [29] that this relation is indeed an approximation.

In [30], it is proved that in addition to GDOP matrix being the covariance of the linearized LS errors, but GDOP matrix is actually the Cramer-Rao bound on estimates of position and clock bias (assuming that pseudorange errors are Gaussian). In [31], Phatak proposes a recursive satellite subset selection method that is based on GDOP and an integrity constraint. DOP is also an important analysis tool in constellation design [32], planning of combined use of different satellite systems [33], or combined use of pseudolites with a satellite system [34].

There are several DOP measures: geometric DOP (GDOP); time DOP (TDOP); vertical DOP (VDOP); horizontal DOP (HDOP); position DOP (PDOP). The name of each suggests the quantity that is (somehow) evaluated through these measures. However, DOP measures cannot contain more than a summary about the geometry’s influence on accuracy of some quantity (position, horizontal position, time, etc.). For selective combining, DOP cannot be used in all-in-view receivers, since DOP measures are monotonically decreasing as the number of satellites increases.
Non-monotonic, weighted DOP or KDOP was suggested to be used in selective combining by the author [11], and it occurs also in [15] under the name enhanced DOP or EDO P. KDOP method suggests an isolation of a signal if KDOP (with the satellite) > KDOP (without the satellite). Thus, the satellite combination with minimum KDOP is selected.

When weighting is used in selection of the satellites, the signal condition is also accounted for which is not usually done in the traditional RAIM approach. For example, using the KDOP method to complement a more traditional approach of FDI results in enhanced accuracy. Figure 3 shows a sample of the results.

FUTURE CONSIDERATIONS AND CONCLUSIONS

Today, the personal GNSS positioning devices are included in or coupled with a cellular phone. Therefore, the computational power of the future receivers is increasing at the same rate as in cellular phones. This will allow more complex methods, integrity monitoring methods, to be included into the receiver. Furthermore, in such a case, cellular networks can be used to assist the integrity monitoring.

The cellular position is a tool for coarse integrity monitoring [16]. Cellular networks are dense in urban areas, providing positioning accuracy of 100-300 meters. This allows harsh integrity monitoring and fastens signal acquisition and decreases time-to-first-fix. In other words, the mere presence of a cellular network can be used to support integrity monitoring in a GNSS receiver. In addition, a cellular network can provide integrity data from an outside source to a GNSS receiver. This has already been standardized [35] in a cellular standard.

In this paper, contemporary solutions in integrity monitoring and selective combining in personal satellite navigation were categorized. Current methods, including FDI, FDE, and KDOP method, and their challenges and limitations, were discussed. The data parameters that are feasible for selective combining were summarized. Effects of recent changes in the field of personal satellite navigation on the task of selective combining were analyzed. Finally, some future predictions were made. Cellular terminals and cellular networks are suggested to have a major role in integrity monitoring in the near future.

It is concluded that, in the future as the computational capacity of the GNSS positioning devices increases and the cellular networks will support positioning, intelligent GNSS receivers can be expected to survive under strict positioning conditions owing to intelligent selective combining schemes while being supported by external and sensor systems.

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FROM THE PRESIDENT

2007 is Upon Us!

A late Happy New Year!
Toward the end of 2006, we received good news on IEEE Membership — AESS membership growth has turned positive. This is very good news and I urge our members to encourage their fellow professionals to join IEEE/AESS. Our growth is in student members. We have two AESS Student Branch Chapters: Portland State University where Jose Bolanos is actively mentoring our student members; and the University of Missouri at Rolla (UMR) where I am helping to re-activate the AESS Student Branch Chapter. David Erdoes, UMR sophomore, has grabbed the reins as interim Chair. The UMR Student Branch Chapter of AESS is looking to participate in an Unmanned Aerial Vehicle (UAV) competition planned for late 2007 in Australia. With the creation of the IEEE Graduate Student Member grade, AESS has the opportunity to reach beyond the traditional departments within universities that support IEEE Student Branches and attract both students and faculty interested in the AESS fields of interest throughout the university. This also has the potential of increasing the number of AESS Student Branch Chapters.

In line with membership improvement, I thank our AESS Board of Governors (BoG) for their efforts: Jim Howard is our VP-Member Affairs, Ron Ogan is our Chapters Chair, Zafar Taqvi is our International Director and Associate VP-Member Affairs, and Bob Rassa is our Executive-VP. They are planning activities in 2007 to enhance the benefits of IEEE/AESS membership.

I take this opportunity to introduce AESS members who have assumed new positions on the BoG: Bob O’Donnell has taken over as VP-Education replacing Saj Durrani, who did an excellent job to bring innovations in continuing education through the Distinguished Lecturers’ Program. Saj also brought in two new IEEE Expert Now tutorials for the IEEE Educational Activities Board. Steve Watkins, from UMR, has agreed to become Assistant VP-Education. He will aid Bob O’Donnell in getting some MIT/Lincoln Labs Radar tutorials set up specifically for AESS members at low cost. Steve has also volunteered to help with our UMR AESS Student Branch Chapter. Joel Walker has taken over as VP-Publications from Ed Reedy. I thank Ed for his many years of volunteerism for AESS, including his role as past president.

AESS looks forward to two important Board of Governors meetings this year. The first will be held in conjunction with the IEEE Boston Section/Radar Conference in April; and the second will be our first BoG meeting outside of North America. It will be held in Edinburgh, Scotland, in October. Hugh Griffiths will lead the way on this one.

Ron Ogan has started the ball rolling on our planned AESS Chapter Summit, which will be held in September 2008, in conjunction with IEEE Sections Congress in Quebec City, Canada. Ron established the first AESS Chapters Summit in conjunction with the 2005 Sections Congress. It was an outstanding success!

Thanks to Paul Gartz, Past President, and others, AESS is financially sound. We will have some funding in 2007 for special projects. Usually, the AESS BoG defines the budget; but this year I solicit input from AESS members regarding any special projects you may wish to pursue with your chapter or section. Here are the boundaries:

- Submit a one-page proposal with an abstract defining your special project;
- Submit it to me via email (j.leonard@ieee.org);
- It must reach me by 1 April 2007 (no fooling!);
- The one-page proposal must include the cost (not more than $5000 to be provided by AESS) and a statement of how it will enhance/improve AESS membership;
- Include planned financial and people support from your local IEEE chapter and section or others in your community.

I will take proposals submitted for special projects from you, our valued AESS members, and present them to our BoG in April. I will ask the BoG to rank them and then select two for implementation. If your proposal is selected, your special project team will receive $2500.00. At the completion of your special project, I will request both a final report and a financial report. When these reports are received, your team will receive the remaining $2500.00. Thank you for this effort.

Good Luck in the new year!

Jim Leonard
President, AESS 2007
IEEE AEROSPACE & ELECTRONIC SYSTEMS SOCIETY ORGANIZATION

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IEEE

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Marina Ruggieri
Theodora S. Saunders
Peter K. Willett

IEEE

REPRESENTATIVES (Other IEEE Entities)

IEEE Publications
• IEEE Press – Russ J. Lefevre
• Journal of Lightwave Technology – D. Chamin & M. Cardinale
• Transactions on Pattern Analysis & Machine Intelligence – J.R. Harris

IEEE Organizational Units
• Sensors Council – M. Wicks
• IEEE-SA, IEEE SCC-20 Hardware Interfaces Sub-Committee (RFI and SATS Standards) – A. Greenspan
• IEEE-USA, Communication & Information Technical Policy – Open
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• IEEE-USA, Transportation & Aerospace Technical Policy – P. Holmer

IEEE Conference Liaisons

• IEEE Aerospace – M. Ruggieri & R.C. Rassas
• IEEE Autotestcon BoD – J. Chapman, W. Downing & D. Wallherrnfechtel
• IEEE International Carnahan Conf. on Security Technology – R.B. Trebits
• IEEE/IAIA Digital Avionics Systems Conf. – C.R. Spitzer & B.C. Breen
• All Radar Conferences – M.E. Davis
• IEEE Position, Location & Navigation Symposium – J.R. Huddie
• International Energy Conversion Engineering – G. Dukermani

IEEE/LIAISONs To Non-IEEE Technical Societies

• American Institute of Aeronautics & Astronautics (AIAA) – C.R. Spitzer
• Association of Old Crows (AOC) – E.C. Gangl
• French Institute of Navigation (SIN) – J.R. Huddie
• German Institute of Navigation (DGN) – J.R. Huddie
• Institution of Electrical Engineers (IEE) Radar, Sonar & Navigation (RSN) Professional Networks (PN) – R.T. Hilt
• Institute of Navigation (ION) – J.R. Huddie
• International Council on Systems Engineering (INCSE) – G. Friedman

IEEE/AESS Website: http://www.eewh.ieee.org/aes
Please send corrections or omissions for this page to the Secretary
FROM THE EDITOR-IN-CHIEF

Engineers Week & Fellows

Engineers Week (EWeek)
18-24 February 2007
Engineers —
Turning Ideas into Reality
At <www.eweek.org>, meet the New Faces of Engineering. These young leaders are making exciting things happen in communities around the world. Local towns also recognize their own engineers for professional and community service with special awards. The National Academy of Engineering presents international awards for engineers’ who have improved our lives. These are the people who have given us the Internet, airplane travel, the implantable cardiac pacemaker, and more.

Nominees for New Faces of Engineering must hold an engineering degree, be employed as an engineer from two to five years, and have been involved in projects that significantly affect public welfare or further professional development and growth. During this EWeek, consider identifying and nominating someone for the 2008 New Faces of Engineering.

In 2004, the IEEE, as the professional society EWeek co-chair with the Fluor Corporation of Aliso Viejo, California, was instrumental in seeking to expand the New Faces of Engineering program to include engineers outside of the United States. IEEE-USA will again play a key role in activities surrounding Engineers Week 2007.

Among activities IEEE-USA is sponsoring are the Best Communications System Award and the essay question for the 15th anniversary of the EWeek Future City Competition in Washington. IEEE-USA also helped with the proposal that led to the IEEE becoming a major sponsor of the new engineering-based PBS television show, Design Squad <http://pbskids.org/designsquad/>, which launches during EWeek.

IEEE Fellow Nominations Due 1 March 2007

Nominations are being accepted for the IEEE Fellows class of 2008. The rank of IEEE Fellow is the institute’s highest member grade bestowed on IEEE senior members who have contributed “to the advancement or application of engineering, science, and technology.” The deadline for nominations is 1 March 2007.

Senior members can be nominated in one of four categories: application engineer/practitioner, research engineer/scientist, educator, or technical leader.

The Fellows website contains additional information on the nomination process including access to the Fellows Nomination Kit, lists of Fellows who may be available as references as well as the history of the IEEE Fellows program. Please visit the Fellows website at: <http://www.ieee.org/fellows>.

— Evelyn Hirt

Candidates for Election to AESS Board of Governors

Eight AESS members will be elected to three-year terms (2007-2009) as members of the AESS BoG at their Spring 2006 meeting. The Nominating Committee is responsible for developing a slate of nominees with the broadest representation of geographic diversity and technical interests of AESS membership. We need your help! We encourage members to suggest candidates with strong professional credentials and dedicated interest in our society’s success. All suggestions are considered.

The requirements for nomination, besides membership in AESS, are the capability and resources to attend at least two BoG meetings per year and to devote several hours per month to AESS affairs. Please send suggestions by February 28, 2007 to Paul Gartz, Nominating Committee Chair, or any officer or BoG member. Addresses, e-mail, and phone numbers are on the inside back cover of this magazine.
February 2007

**Distinguished Lecturers Program**

**James R. Huddle, Chair**

All AESS Chapters and IEEE Sections are encouraged to take advantage of the AESS 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 $550 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 AESS, it should contact James R. Huddle. As soon as the meeting has been announced, an email or letter should be sent to the speaker providing all the necessary information about the meeting. 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.

<table>
<thead>
<tr>
<th>Title</th>
<th>Name</th>
<th>Contact Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Control Technology Applied to Aircraft &amp; Automobiles</td>
<td>Dr. Kimio Kanai, National Defense Academy of Japan</td>
<td>81-45-812-1244 (V&amp;F) <a href="mailto:k-kimio@mcb.biglobe.ne.jp">k-kimio@mcb.biglobe.ne.jp</a></td>
</tr>
<tr>
<td>Avionics for Manned Spacecraft</td>
<td>Dr. Myron Kayton, Kayton Engineering Co.</td>
<td>(310) 393-1819 (310) 393-1326 F <a href="mailto:m.kayton@ieee.org">m.kayton@ieee.org</a></td>
</tr>
<tr>
<td>Evolution of Aircraft Avionics</td>
<td></td>
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<tr>
<td>Navigation: Land, Sea, Air and Space</td>
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<tr>
<td>One Hundred Years of Inertial Navigation Practitioner’s View of System Engineering</td>
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<td></td>
</tr>
<tr>
<td>Bistatic &amp; Multistatic Radar</td>
<td>Dr. Hugh D. Griffiths, University College, London</td>
<td>+44-20-7679-7310 +44-20-7388-7325 F <a href="mailto:h.griffiths@ee.ucl.ac.uk">h.griffiths@ee.ucl.ac.uk</a></td>
</tr>
<tr>
<td>Synthetic Aperture Radar</td>
<td></td>
<td></td>
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<tr>
<td>Current Advances in Radar Technology</td>
<td>Robert T. Hill, Consultant and Lecturer</td>
<td>(410) 770-4535 (V&amp;F) <a href="mailto:janebhill@man.com">janebhill@man.com</a></td>
</tr>
<tr>
<td>Evolution of Inertial Navigation</td>
<td>Dr. Itzhak Bar-Itzhack</td>
<td></td>
</tr>
<tr>
<td>Future of Electronic Warfare and Modern Radar Signals</td>
<td>Dr. Richard G. Wiley, Research Associates of Syracuse</td>
<td>(315) 463-2266 (315) 463-8261 F Dick <a href="mailto:Wiley@aol.com">Wiley@aol.com</a></td>
</tr>
<tr>
<td>Multisensor Data Fusion</td>
<td>Dr. Pramod Varshney, Syracuse University</td>
<td>(315) 443-4013; (315) 443-2583 F <a href="mailto:varshney@syr.edu">varshney@syr.edu</a></td>
</tr>
<tr>
<td>National Missile Defense and Early Warning Radars</td>
<td>Larry Chasteen, University of Texas at Dallas</td>
<td>(972) 234-3170; (972) 883-2799 <a href="mailto:chasteen@utdallas.edu">chasteen@utdallas.edu</a></td>
</tr>
<tr>
<td>Novel Orbits &amp; Satellite Constellations</td>
<td>Dr. Daniele Mortari, Texas A&amp;M University</td>
<td>(979) 845-0734 <a href="mailto:mortari@aero.tamu.edu">mortari@aero.tamu.edu</a></td>
</tr>
<tr>
<td>Radar — Past, Present and Future</td>
<td>Dr. Eil Bookner, Raytheon</td>
<td>(978) 440-4007 (978) 440-4040 F <a href="mailto:Eil_Bookner@raytheon.com">Eil_Bookner@raytheon.com</a></td>
</tr>
<tr>
<td>Satellite Communication Systems</td>
<td>Dr. S.H. Durrani, Consulting Engineer</td>
<td>(301) 774-4607 (V&amp;F) <a href="mailto:s.durrani@ieee.org">s.durrani@ieee.org</a></td>
</tr>
<tr>
<td>System Engineering for International Development for the 21st Century</td>
<td>Paul Gartz, Boeing Co.</td>
<td>(206) 954-9616 <a href="mailto:p.gartz@ieee.org">p.gartz@ieee.org</a></td>
</tr>
<tr>
<td>Target Tracking and Data Fusion: How to Get the Most Out of Your Sensors</td>
<td>Dr. Yaakov Bar-Shalom, Univ. of Connecticut</td>
<td>(860) 486-4823 (860) 486-2285 F <a href="mailto:ybs@engr.uconn.edu">ybs@engr.uconn.edu</a></td>
</tr>
</tbody>
</table>

All data on this page is under the purview of James Howard, VP-Member Affairs. Please send all corrections and omissions to him at the address on the inside back cover.
Chapter News

Calling All Chapters
The Distinguished Tutorials Program

Sajjad H. Durrani

The Distinguished Tutorials Program (DTP) was first announced in the June issue of Systems. It is my great pleasure to report that several Sections have expressed considerable interest in it, and some are currently in touch with Distinguished Instructors (DIs) to schedule a tutorial.

To recap the concept:

The DTP allows a Section or an AESS Chapter to invite a DI to give a tutorial at no cost to the hosts. The AESS picks up the DIs travel cost and pays an honorarium; this allows our members to benefit from tutorials normally presented at major conferences, but are not available locally at a date convenient for the hosts.

The Program was approved by the AESS Board of Governors in April and we budgeted for two such Tutorials this year. Due to the better-than-expected response, we will try to obtain funds for three or more Tutorials in 2007. Similarly, the program started with five Tutorials, but four more have been added since. The current listing includes the DI’s topic, the DI’s name, affiliation, and e-mail addresses.

Automated Testing
Michael Ellis, Northrop Grumman Corporation,
mtellis@aol.com

GPS and Inertial Data Processing
James Farrell, VIGIL, Inc.,
navaide@comcast.net

Systems Approach to Engineering Projects
Paul Gartz, Boeing Corporation,
p.gartz@ieee.org

Design and Use of Small Satellites in Education
Albert Helfrick, Embry Riddle Aeronautical University,
helfrica@erau.edu

Advances in Radar Technology
Robert Hill, Consultant,
janebobhill@msn.net

Navigation – Land, Air and Space
Myron Kayton, Consulting Engineer,
m.kayton@ieee.org

Space-Time Adaptive Processing
for Surveillance Radar System
Michael L. Picciolo, SAIC,
Michael.L.Picciolo@saic.com

Digital Avionics
Cary Spitzer, Consultant,
c.spitzer@avionicon.com

Radar Reflectivity
Robert Trebits, Georgia Tech,
bob.trebits@gmail.com
### IEEE 2007 AESS MEMBERSHIP APPLICATION

**MEMBERSHIP APPLICATION**

(Current renewing IEEE members joining AESS complete areas 1, 2, 7, 8)

Mail to: IEEE, Member & Member Services Dept., 445 Hoes Lane, P.O. Box 8801, Piscataway, New Jersey 08855-8801 USA

- Fax: (732) 981-0225 (credit card payments only)
- E-mail: renew@ieee.org or www.ieee.org/join

---

**1. NAME AS IT SHOULD APPEAR ON IEEE MAILINGS: SEND MAIL TO:**

- [ ] Home Address
- [ ] Business/School Address

If not indicated, mail will be sent to home address. **NOTE:** Enter your name as you wish it to appear on membership card and all correspondence.

**PLEASE PRINT. Do not exceed 40 characters or spaces per line. Abbreviate as needed. Please circle your last/surname as a key identifier for the IEEE database.**

<table>
<thead>
<tr>
<th>TITLE</th>
<th>FIRST OR GIVEN NAME</th>
<th>MIDDLE NAME</th>
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**POSTAL CODE**

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**2. Are you now or were you ever a member of IEEE?**

[ ] Yes  [ ] No

If yes, please provide, if known:

<table>
<thead>
<tr>
<th>MEMBERSHIP NUMBER</th>
<th>GRADE</th>
<th>YEAR MEMBERSHIP EXPIRED</th>
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**DEMOGRAPHIC INFORMATION — ALL APPLICANTS —**

**Date of Birth:**

[ ] Male  [ ] Female

**Day**  **Month**  **Year**

---

**3. BUSINESS / PROFESSIONAL INFORMATION**

**Company Name**

**Department / Division**

**Title / Position**  **Years in Current Position**

**Years in the Profession Since Graduation**

[ ] PE  [ ] State / Province

**Street Address**

**City**  **State / Province**  **Country**

**Postal Code**

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**4. EDUCATION**

A baccalaureate degree from an IEEE reference list of programs assures assignment of "Member" grade. For others, additional information and references may be necessary for grade assignment.

<table>
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<th>Baccalaureate Degree Received</th>
<th>Program / Course of Study</th>
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<th>Highest Technical Degree Received</th>
<th>Program / Course of Study</th>
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**5. SIGNATURE OF APPLICANT**

<table>
<thead>
<tr>
<th>Hereby make application for IEEE membership and agree to be governed by IEEE’s Constitution, Bylaws, Statements of Policies and Procedures and Code of Ethics.</th>
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<tr>
<th>Full signature of applicant</th>
<th>Date</th>
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**6. CONTACT INFORMATION**

<table>
<thead>
<tr>
<th>Office Phone</th>
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<th>Office Fax</th>
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<th>Office E-mail</th>
<th>Home E-mail</th>
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**7. 2007 IEEE MEMBERSHIP RATES**

**Check (/) / a box**

<table>
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<tr>
<th>16 Aug 2006</th>
<th>1 Mar 2007</th>
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<th>28 Feb 2007</th>
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**Residence**

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<td>United States</td>
<td>$161.00 $ 80.50</td>
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<tr>
<td>Canada (includes GST)*</td>
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<tr>
<td>Canada (includes HST)*</td>
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<tr>
<td>Africa, Europe, Middle East</td>
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<td>Latin America</td>
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<tr>
<td>Asia, Pacific</td>
<td>$128.00 $ 64.00</td>
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*IEEE Canadian Business NO. 12583418B
**If application is to be received by IEEE after 16 August pay full year.

Subscriptions to Spectrum (4 times/year) and the magazine are included in dues.

---

**8. 2007 AESS MEMBERSHIP RATES**

**Aerospace and Electronic Systems Society**

**Membership Fee**

| $ 25.00 |

---

**Includes AES Magazine**

- (print & electronic included in membership fee)
- Online access to IEEE/OSA Journal of Lightwave Technology
- Publications available only with AES membership:
- Transactions on:
  - Aerospace and Electronic Systems
    - Print $ 25.00
    - Electronic $ 25.00
  - Pattern Analysis and Machine Intelligence
    - Print $ 25.00
    - Electronic $ 35.00
  - Journal of Lightwave Technology
    - Print $ 45.00
  - IEEE/OSA
    - Amount Paid

---

**METHODS OF PAYMENT**: Prices stated are in US dollars

- [ ] Credit Card — American Express, VISA, MasterCard, Diners Club
- [ ] Check  [ ] Bank Drafts  [ ] Money Orders Payable on a US bank

---

**IEEE Membership Dues**

[ ] $  

**IEEE Aerospace and Electronic Systems Society Fees Total**

[ ] $  

**Canadian residents pay 7% GST or 15% HST on Society fees only. Reg. No. 12583418B**

**TAX**

---

**AMOUNT PAID WITH APPLICATION**

<table>
<thead>
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<th>TOTAL $</th>
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**Prices stated are in US dollars; subject to change without notice.**

- [ ] Check or money order enclosed (Payable to IEEE)
- [ ] American Express  [ ] VISA  [ ] MasterCard
- [ ] Diners Club

---

**Charge Card Number**

**Cardholder 5 Digit Zip Code**

**Ex., Date**  **Billing Statement Address**

**M/C/Yr.**  **VISA Only**

<table>
<thead>
<tr>
<th>Full signature of applicant using credit card</th>
<th>Date</th>
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