I&M in Navigation Systems

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Thanks to the advancements made over the years in several areas of engineering, navigation-based services are ubiquitous. Requirements on the services are even tighter in recent times because of the expectations to have the ability to navigate anywhere and anytime, even in indoor environments, where the usual outdoor global positioning systems cease to offer reliable information. Thus, new areas of application research are emerging, e.g., indoor navigation and positioning, location-based services, navigation for impaired people and in ambient assisted living environments. Specific established domains, such as airborne and naval applications, or navigation for robotic applications benefit from new technologies and their results. This framework of technologies will be completed by the expected deployment of new infrastructures, such as the European Union's Galileo Global Navigation Satellite System (GNSS), or the operational improvements in the Russian GLONASS, and the advancements made in the realization of the Chinese GNSS, the BeiDou [1], not to forget the U.S. government's GPS, as the first accessible GNSS. Business markets also offer motivations for applied and theoretical research in this subject, with 200 new startup companies in recent years, according to [2].

Since the basis of navigation location, i.e., on positioning and orientation measurements, in recent years the *IEEE Transactions on Instrumentation and Measurement* (TIM) has experienced a significant increase in the number of papers – both submitted and accepted – in this field. Unfortunately, many submitted papers have been rejected because they fall clearly outside the journal scope. This fact motivated us – as researchers in the field involved in the Editorial Committee of the journal – to write this paper to specify what can be considered an I&M technical contribution in the field of navigation systems.

Navigation Systems Basics

A possible navigation system based on *anchors* is represented in Fig. 1. These represent beacons of known position, to be used by the receiver for referencing purposes. By using the known information about the position of the anchors, the receiver is able to estimate navigation information, e.g., position and speed, by measuring the relative distance from each anchor. Then, the known position is used for navigating the user to the final destination. Anchors may represent satellites in a GNSS, or fixed position beacons in indoor positioning systems based on ZigBee, Bluetooth, ultra-wide bandwidth, or magnetic technologies [2], [3].

According to the technology used, the relative distance between the receiver and the anchors is estimated by measuring the time interval needed by signals with given format (e.g., short-time pulses) to travel from the anchors to the receiver or by the intensity of the signals received by the user [3], [4].

Instead of using anchors for navigation purposes, there are other approaches to take. These include the usage of ultrasound or laser signals to measure distance by the time needed by pulses to be echoed by nearby objects and image processing-based techniques that extract position information from images captured by cameras. Signal processing of acquired data is highly dependent on the technique used to estimate distances and encompasses a wide range of approaches needed to compensate for known disturbing effects and to estimate the required parameters. Ultimately, a measurement instrument is built to provide measurement results on position and speed.

Current Trends and Applications

TIM has published several papers on the wide subjects covered by indoor/outdoor navigation and positioning. Consider

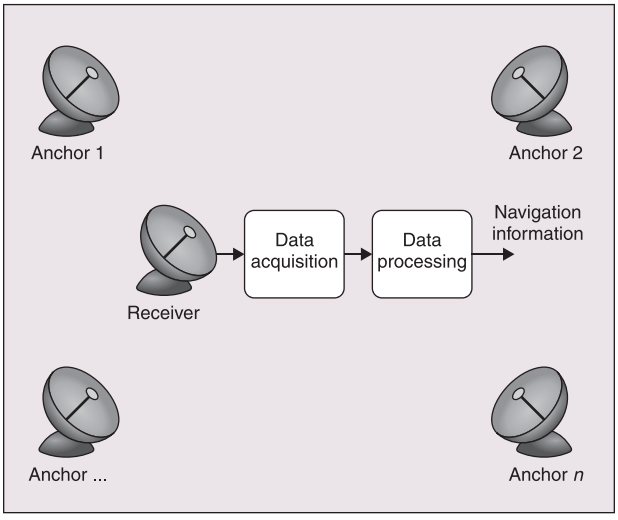

Fig. 1. A typical anchor-based navigation systems.

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that papers which appeared in TIM over the period 2009–2014 and included the terms 'navigation', 'positioning' or 'localization' in the title amounted to 18, 42 and 31, respectively. In the same period, the amount of papers containing the above terms in metadata were 83, 288 and 68, respectively, with an increasing trend over the last few years.

A sample list of papers, containing details about the presented systems, is reported in the references. It indicates that current research is strongly focused on indoor rather than outdoor only navigation [5], [6]. Since there is no dominant technology to realize an indoor navigation and positioning system, the papers appearing in TIM cover a wide set of different approaches and technologies, such as magnetic field sensors [7], ad-hoc UWB sensors [3], [8], ultrasounds [9], wireless RSS, and time-of-flight [10], [11], AC magnetic field sensors [4] and so on. The algorithms used for signal processing are also diversified according to the type of data available for navigation purposes: while [5] and [10] use data fusion approaches, fingerprinting is used in [7], minimum square error-based techniques are used in [3] and [8], and alignment methods are used in [14]–[16].

The coexistence of very different approaches accounts for the current level of ferment in choosing the best technology for a given application, but also limits the possibility to adopt a more specific classification criterion. However, in each case, uncertainty in determining the position used for navigation purposes remains one of the primary foci of the paper contents.

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Given the amount of systems engineering aspects in terms of hardware, software and processing issues, the interest of the I&M scientific community can be focused on several subjects. For instance, improvements in the data acquisition subsystem to measure time intervals or signal intensities with higher accuracies and precision require such aspects to be considered in a paper on this topic. Moreover, any issue regarding the design and measurement of parameters associated with the behavior of antennas and the generation and reception of pulses transmitting time information is also a subject of possible interest for the I&M community. In addition, metrological characterizations of algorithms used to estimate locations are of sure interest, as well as advances in the state-of-the-art derived from such an analysis. Anyway, the focus of such papers should be on performance analysis and characterization of the described navigation system in comparison with other such systems, rather than being oriented only to design issues and related details.

As in any measurement system, metrological characterization of navigation systems requires the following steps:

- define the relevant parameters of the system, as uncertainty in different operating conditions and response time; and
- design and implement a calibration process capable to provide the parameters of interest of the considered system; usually an environment similar to the expected operating environment is considered and data returned by the system under calibration are acquired, processed, and compared with reference data.

Uncertainty Analysis

According to the most relevant documents in metrology; i.e., the International Vocabulary of Metrology (VIM) [12] and the Guide to the Expression of Uncertainty in Measurement (GUM) [13], measurement uncertainty is an essential part of any measurement results. Hence, papers dealing with I&M issues in navigation systems need to analyze the effect of the system on the uncertainty of the measurement process. Measurement uncertainty is defined as a "parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand" [13].

The GUM suggests describing uncertainty using the framework of probability theory. In particular, the use of the probability density function is proposed to represent the dispersion of measurement values. In particular, uncertainty is quantified by an estimate of the related standard deviation, called *standard uncertainty*.

When analyzing a novel navigation or location system or a part of it (e.g., the data acquisition system or a data processing algorithm) from an instrumentation and measurement perspective, the different sources of measurement uncertainty must be identified and their effects on measurement results must be evaluated. Specifically, at first, all significant systematic effects must be identified and removed. Then, the overall combined standard uncertainty associated to the measurement result has to be determined by a suitable combination of all of the identified contributions [13]. Indeed, this procedure is the only universally accepted approach for the metrological characterization of any measuring system.

It is worth noticing that navigation uncertainty is due not only to the measuring system properties, but also to the model adopted for the description of the navigation path in the environment. A third kind of uncertainty source is represented by the interactions between the measuring system and the environment, justifying the so-called loading effect. Of course, the usage of analytical approaches or computer simulations can help in performing uncertainty analyses. However, results should always be validated by means of a suitable calibration process.

Contents of Papers on Navigation Systems of Interest for TIM

As stated on the IEEE I&M Society website, TIM publishes research papers:

that address innovative solutions to the development and use of electrical and electronic instruments and equipment to measure, monitor and/or record physical phenomena for the purpose of advancing measurement science, methods, functionality and applications.

Thus, the technical content of papers submitted to TIM are expected to clearly satisfy these requirements, mainly:

- by performing a proper metrological characterization and uncertainty analysis of the considered navigation system or part of them;
- by referring to the recent literature (and especially to qualified international journals) in the field of I&M in the considered or related subjects; and
- by comparing (theoretically, with simulation or experimental results) the performance of the proposed contribution with published results, clearly highlighting the novelty of the proposal and emphasizing the advancement with respect to the state-of-the-art in the I&M field.

Therefore, papers whose core contribution is strictly in electronic system design, signal processing, propagation, or so on, without any significant I&M content are outside TIM's scope. For example, a paper that presents an algorithm providing a new location estimation technique, without properly characterizing its performance with respect to the state-of-the-art in terms of contribution to measurement uncertainty, cannot be considered falling within the TIM's scope. Such a contribution should not be submitted to TIM, and it should be directed to an appropriate journal in the Signal Processing field. Conversely, a paper that proposes a location estimation technique and then shows (possibly using both simulation and experimental results) that it is more accurate than state-of-the-art algorithms is surely of interest for TIM readers. Indeed, not just the proposal of new algorithms but also their performances, and specifically their uncertainty, dynamic characteristics, or computational efficiency are important from the I&M perspective.

Conclusions

The proliferation of commercial proximity sensors and the invention and deployment of new systems able to find position and attitude information of sensors within buildings are becoming enabling technologies for the creation of new real-time position aware services. The community of researchers in the area of instrumentation and measurement is playing an active role in improving knowledge and understanding of the associated phenomena.

In this paper, we illustrated the major aspects to be considered when thinking about publishing an article in the *IEEE Transactions on Instrumentation and Measurement*. When this is the case, systems are considered instruments that need to be characterized in terms of measurement models and associated measurement uncertainties, whose role must be underlined to meet the scope of the *IEEE Transactions on Instrumentation and Measurement* and the expectations of its typical readers.

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