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Indoor and outdoor positioning system based on navigation signal simulator and pseudolites

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Abstract

In positioning technology, indoor positioning is known as the "last kilometer" problem because the global navigation satellite system (GNSS) cannot work indoors. A wide range of indoor positioning technologies have been developed, notably Bluetooth and Wi-Fi, and others using LED and ultra-wideband light sources. Although these technologies have had good success indoors, the indoor use of GNSS is still being pursued, and an indoor and outdoor joint location system remains a development aim. In this paper, we propose a new indoor positioning scheme that adopts pseudo-satellite (pseudolite) technology combined with a navigation signal simulator. Positioning is achieved by indoor pseudolite antennas that transmit the 'actual' satellite signals in space handled by the navigation signal simulator to an indoor user. However, the 'actual' satellite ephemeris stored in the pseudolites will bring false pseudoranges, which makes it necessary to adopt map matching technology to determine the real position. The results of our computer simulation showed that when the measurement error mainly multipath error in the room was within 1 m, the positioning results were better than 2 m in about 94% of instances. The proposed method provides a feasible solution for indoor and outdoor joint positioning. The advantages of this system include a better dilution-of-precision (DOP) than an independent pseudolite system indoors, no singular matrix, and initial point selection without limitation in the positioning equation. In addition, the introduction of a navigation signal simulator makes the system more flexible.

Keywords: Indoor positioning; Navigation signal simulator; Pseudolite; Map matching

1. Introduction

Mautz (2012) and Zhao et al. (2014) have produced comprehensive overviews of a wide range of indoor positioning technologies. Of these, Wi-Fi (Liu et al., 2014), and Bluetooth (Lee et al., 2014) technologies have been the fastest growing. There are also indoor positioning technologies that exploit radio-frequency identification, ultrasound, and infrared, ultra-wideband and LED light sources.

In addition to traditional indoor positioning techniques, research has focused on a variety of hybrid positioning methods, including a GPS and inertial navigation combination (Lee et al., 2002), and the development of new outdoor positioning systems to enhance indoor services, such as LOCATA (Barnes et al., 2003.). The application of GNSS-like signals to indoor positioning has produced two different systems: assisted global navigation satellite systems (A-GNSS) (Duffett-Smith and Rowe, 2006), and pseudolite systems (pseudo-satellites). With A-GNSS, the core approaches are either to transfer the navigation message to the indoors via a communications network, or to improve the sensitivity of the receiver. However, increasing

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the sensitivity of the receiver reduces its anti-jamming capabilities. Also, the positioning results will probably be less accurate as a result of the multiple signal paths. With the pseudolite indoor positioning system, which transmits signals from a local ground-based positioning system, the first consideration is to create a complement to the GPS constellation when the number of satellites is less than three. There are broadly three system types: pseudolite, repeater, and repealite (Samama, 2011). The most representative application of the pseudolite system is the carrier-phase differential GPS (CDGPS) positioning system developed by Kee et al. (2003), which uses indoor asynchronous satellites. The repeater system is designed to solve problems caused by the near-far effect, multipath signals, and pseudolite synchronization (Jee et al., 2004; Im et al., 2006). The system receives GPS signals from an outside antenna and uses transmitters working on different time slices to transmits real signals into the room. The repealite system is a hybrid that combines the advantages of both pseudolite and repeater systems (Vervisch-Picois and Samama, 2012). New pseudolite-based indoor positioning schemes have also been developed. These include a scheme that receives real-world GPS signals, repeats each of the satellite signals, and transmits them into the room using indoor transmitting antennas (Xu et al., 2015). Analyzing these indoor positioning schemes based on pseudolites allows us to establish some general limitations. For example, they do not effectively use ephemerides, and usually employ other means such as a total station to calculate the location coordinates for the interior layout of the pseudolite antennas. Indoor and outdoor continuous positioning cannot be provided to the user because the antenna position calibrated by the total station has not been converted into ephemeris information. A post-processing method is used to calculate the user's location by processing the coordinates of the pseudolite antennas and the pseudorange information. The contribution of this article is through its ephemeris modification, binomial fitting time delay, and map matching method, making it possible to realize indoor and outdoor seamless positioning based on pseudolite technology.

2. System design strategy

Pseudolite technology was introduced in the 1980s, but so far it has not been widely utilized. This is a result of problems with four aspects of the technology: the time synchronization technique, fixed satellite position message broadcast technology, the multipath effect, and the near-far effect. Regarding the first problem, the crystal oscillator in the pseudolite has low stability, which makes it impossible to achieve the same time synchronization relationship as with navigation satellites. Second, the setting of the navigation ephemeris is for high-speed satellites, but pseudolites are stationary and near the ground, which makes it difficult for them to handle ephemeris information. Third, the multipath effect is more severe in an interior space than in an outdoor environment. The pseudorange error caused by the multipath effect has become the largest range error factor in indoor positioning, affecting the positioning accuracy, and short delay multipath is the most troublesome problem because it is difficult to use a parameter estimation method such as MEDLL technology (Townsend et al., 1995) or a narrow correlation technique such as the narrow correlator (Van Dierendonck et al., 1992). Regarding this last point, the near-far effect is a phenomenon in which the power of pseudolites transmitting signals in the vicinity can affect the reception of distant pseudolite signals. In an outdoor environment, this can be overcome by changing the antenna pattern gain; however, we usually choose patch antennas which have the same gain in designing indoor positioning systems in terms of cost and complexity. We use different methods to solve or mitigate the above problems. For example, our pseudolite clocks were derived from the same simulator clock so that there is strict time synchronization. In addition, we mitigated the near-far effect and fixed satellite position message by changing the network structure of the pseudolite antennas and ephemeris. Meanwhile, because the navigation signal power was low, the signal did not leak to the outside and result in legal questions. Clearly, these solutions will play an important role in the commercialization of pseudolites.

In this paper, we introduce a type of positioning technology that is both indoor and outdoor compatible. It relies on a navigation signal simulator and pseudolites to bring real navigation satellites into the room. It also combines binomial curve fitting and map matching to achieve indoor positioning.

GNSS requires at least four visible satellites to achieve positioning without timing. The system presented is based on the navigation signal simulator, which provides the same clock source for all the pseudolites. Each pseudolite stores the real broadcast ephemeris through the simulator shown in Fig. 1.

Use of pseudolites allows an indoor positioning system that is similar to an outdoor GNSS to be built, but because the pseudorange of the indoor positioning system is not the real pseudorange, it is based on measuring the difference between the system's pseudorange and the real pseudorange. The system's pseudorange is the sum of pr_1 and sr_1 (solid line plus broken line in Fig. 1) instead of the true pseudorange ssr_1 from the actual satellite to the user (dot-dashed line in Fig. 1). Note that here we can regard the ephemeris information stored within a pseudolite as being the same as the information stored in the actual orbiting satellite. However, the actual satellite orbit parameters such as the orbit error, the satellite clock error, and ionospheric and tropospheric errors do not exist in the pseudolite-based system. Two critical questions arise: 1. How can we represent the time delay $\Delta\tau_{sr_1}$ from the actual satellite to the pseudolite? 2. How does the bias of the system pseudorange affect the result of a positioning? Indeed, how is the true user location to be determined? In addition, the pseudolite antenna