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UAV Navigation Using Signals of Opportunity in Urban Environments: An Overview of Existing Methods

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Abstract

With Unmanned Aircraft System (UAS) being developed and deployed for an increasing number of applications, it is essential to meet demanding separation assurance and navigation performance requirements, especially considering the current evolutions of the UAS Traffic Management (UTM) research framework. However, in dense urban environments characterized by tall buildings and complex man-made structurs, Global Navigation Satellite System (GNSS) is prone to data degradations or complete loss of signal due to multipath effects, interference or antenna obscuration. Furthermore, there is always a risk of jamming and spoofing of GNSS signals, with low cost civilian GNSS receivers being more vulnerable to a spoof attack. Therefore, a number of Signals of Opportunity (SoOP) techniques are being explored to improve the navigation performance when UAS are employed in urban canyons. Electromagnetic signals found in urban environments including analogue/digital radio, analogue/digital television, Wi-Fi, Global System for Mobile Communications (GSM) and Code Division Multiple Access (CDMA) based signals are considered to model the system performance parameters. Implementation methods for exploiting SoOP such as Angle of Arrival (AOA), Time of Arrival (TOA), Received Signal Strength (RSS) and Time Difference of Arrival (TDOA) are introduced and compared. Integration of SoOP techniques in novel low-cost Navigation and Guidance Systems (NGS) is also investigated. As SoOP are not natively intended to be used for navigation purposes, no single source of SoOP for navigation can work in all environments and hence a SoOP source has to be selected based on specific requirements in the considered urban environment. Constraints of power and weight on the Unmanned Aerial Vehicle (UAV) besides hardware and software costs are also factors that are considered when selecting appropriate SoOP signal sources. Therefore, there is a clear opportunity for considerable savings in both infrastructure and energy costs by providing a low-cost and low-volume integrated NGS solution for trusted autonomous aerial operations.

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Keywords: Signals of Opportunity; UAV; Navigatipon and Guidance systems; urban canyons

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1. Introduction

Unmanned Aerial Vehicles (UAV) are increasingly being used in scenarios considered "dull, dirty or dangerous" for manned aircraft. This could, in many situations, require the UAV to navigate thorough urban landscapes, consisting of tall buildings and complex man-made structures. On-board UAV navigation primarily relies on Inertial Navigation Systems (INS), in conjunction with Global Navigation Satellite Systems (GNSS) receivers, though research is increasingly supporting the integration of Vision-Based Navigation (VBN) sensors and other low cost sensors like acoustic, magnetic and GNSS for Attitude Determination (GAD). In urban environments, GNSS signals are prone to data degradations that could also result in the complete loss of data in some situations [1-4]. Owing to this, there has been an increasing research focus on utilizing SoOP for NGS.

Various signal sources have been identified for UAV navigation and guidance applications in dense urban environments. Analogue/digital radio, analogue/digital television, Wi-Fi and GSM/CDMA signals have shown potential for being used as SoOP for navigation [5, 9-14]. The implementation methods for using signals of opportunity are Angle of Arrival (AOA), Time of Arrival (TOA), Received Signal Strength (RSS) and Time Difference of Arrival (TDOA) [5, 12].

This research focusses on adopting various SoOP signals available in the urban environments and the ways to utilize them. All potential SoOP signal sources are described with the implementation method employed to get the navigation data from the signal. The advantages and limitations of using a particular SoOP signal source for navigation and guidance are also discussed. After explaining the various SoOP implementation methods and their use for a particular signal, the paper sums up the findings and lays down the path for future research.

2. SoOP sources

2.1. Television signals

Television signals are a good candidate as SoOP for navigation. Digital terrestrial service works with analogue TV transmissions allocated on VHF (Very High Frequency) and UHF (Ultra High Frequency) part of the frequency system. However, with more viewers shifting to digital TV, the usage of analogue TV has greatly declined. The signal structure standards of digital television used globally are Advanced Television Systems Committee (ATSC) in North America, Digital Video Broadcasting (DVB) in Europe, Australia and large parts of Asia, Integrated Services Digital Broadcasting-Terrestrial (ISDB-T) in Japan and Digital Terrestrial Multimedia Broadcast (DTMB) in China [13-16]. GNSS can be suitably complimented by TV signals based localization system in an urban environment where GNSS tends to fail. The broad coverage and high transmission power of TV signals makes it possible to achieve low Horizontal Dilution of Precision (HDOP) for navigation [17]. The TV signals have a much higher bandwidth of 6-8 MHz, which helps mitigate effects of multipath [17, 18]. Low and diverse frequencies and high power of TV signals make them ideal for indoor and urban reception [19].

However, transmitted TV signals lack inclusion of transmission time information or time stamps. Transmitter clocks in TV transmitters are quite unstable with large drifts in oscillators causing large frequency offsets [10, 19]. To overcome the errors in transmission time, a network of regional monitor stations has been suggested, which can broadcast the corrected timing information for each TV station [19]. Setting up monitor stations will involve a huge expenditure. So, using TDOA, with two receivers, seems more practical for TV signals. Since both the receivers are proposed to be fitted on the UAV, the requirement of a large bandwidth between the two can be comfortably met.

2.2. Audio signals

Studies have been conducted on using both analogue (FM and AM) and digital audio signals for navigation [9, 20, 21]. The standards for digital audio are iBiquity in United States, Digital Audio Broadcasting (DAB) in Europe and Australia, and ISDB-T in Japan [22]. The advantage of using audio signals for navigation are low cost of hardware, low power requirements at the receiver side, high transmission power, good reception in urban areas (both indoor and outdoor) and availability of large number of transmitters.