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Evaluation of Synthetic Aperture Radar Satellite Remote Sensing for Pavement and Infrastructure Monitoring

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Abstract

This study aims to carry out investigation of the capability of Synthetic Aperture Radar (SAR) satellite data and interferometric synthetic aperture radar (InSAR) for use in advanced infrastructure monitoring, which is a tangible breakthrough allowing to assess pavement deformations and deformation velocities with millimetric accuracy. Recent developments in satellite remote sensing and availability of high-resolution SAR products have created an opportunity for SAR-based monitoring in pavement and infrastructure management. Therefore, SAR-based monitoring has become valuable for monitoring and rehabilitating the nation's deteriorating roadway infrastructure elements such as bridge settlements and displacements, roadway surface deformations, geohazards and sinkhole detection, historical analysis of problematic sites, etc. In this research study, the feasibility, and effectiveness of use of satellite remote sensing technology for pavement and infrastructure monitoring were evaluated. A cost benefit analysis for a possible SAR-based monitoring system was performed. It was found that SAR-based methods are useful as a complementary tool rather than a replacement for current technologies and practices, specifically in the sense of state of good repair.

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Keywords: Synthetic Aperture Radar; InSAR; Pavement Monitoring; Satellite Remote Sensing

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1. Introduction

As a vital part of the system, adequate infrastructure is an essential precondition for complex and dynamic transportation systems. Aging transportation infrastructures in the U.S. emphasizes the importance of preserving the existing assets and maintaining the transportation system in sustainable level. Researches indicate that 65% of the roadways are rated as “less than good condition” and 25% of bridges require “significant repair” in the U.S. [1]. The Federal Highway Administration (FHWA) has estimated the necessary annual investment of $77 billion for federal-aid highway system compared to federal highway receipts of $34 billion as of 2014 [2]. Budget limitations and decreased revenues have made extremely difficult for many states to maintain the state of good repair on roadways.

Traditional pavement inspection techniques offer a method of determining the pavement condition through observing and recording, which causes this pavement survey work to be cumbersome and inefficient. In fact, some of these periodic inspection-based monitoring efforts are redundant and some of them cause late-detection of the problems which cause money and energy loss. Therefore, any contribution towards network-scale monitoring tools that facilitate the early detection of the problems and reduce the vehicle-based inspection trips to the sites will help building more robust and effective monitoring programs. Such tools will benefit state and federal agencies to prioritize their investment strategies that will yield economic and other benefits.

In the last two decades, SAR technology and Interferometric Synthetic Aperture Radar (InSAR) applications have been widely investigated for large-scale monitoring studies and mature fields for SAR applications have been summarized by Ouchi [3]. Recently, availability of high-resolution SAR images and developed advance data processing methodologies has taken the attention of transportation research community. With these developments, extracting the information about the identity and extent of the problems at the targeted scene became possible for relatively small areas, which makes the technique useful for pavement and infrastructure monitoring.

In the light of current infrastructure and pavement monitoring practices, this study aims to investigate the capability of satellite remote sensing technologies, specifically SAR satellite data for use in advance infrastructure monitoring, which is tangible breakthrough in sensing technology allowing to assess deformations with millimetric accuracy. Scope of this research is limited to the evaluation of the possibility of using SAR-based systems, data sources and SAR image analysis tools for pavement and infrastructure monitoring in general and does not include the effectiveness of such systems for detecting different type and severity of pavement surface distresses and infrastructure problems which require further exploration.

2. Current Pavement and Infrastructure Monitoring Technologies

Pavement condition surveys provide an indication of the physical condition of the pavements and consist of data collection, pavement condition rating and quality management elements. Both manual (human observations) and automated (line and area scanners, ground penetrating radars, acoustic sensors, optical imagery, LIDAR, etc.) data collection techniques are widely used based on agencies’ priorities, available resources and geographic limitations. The condition ratings are then used for estimating and managing the rehabilitation and maintenance works, long-term economic planning and historical pavement performance records. Pavement condition data has been collected in variety forms, however, most common data types could be categorized as distress data, structural capacity data, ride quality data and skid resistance data as suggested by Attoh-Okine and Adarkwa [4]. Distress data and ride quality data were found relevant for considering the potential contribution of SAR based monitoring.

Two critical challenges in pavement management are the timely detection of problems and frequency data collection. Many studies and experiences of agencies show that early detection of problems treated with preventive measures increase the service life of the assets and reduce the total maintenance cost while maintaining the safety and quality [5]. Haider et al. [6] stated that “longer monitoring intervals may underpredict the expected roughness and overpredict the expected life on the basis of roughness” and highlighted the importance of early detection of problems for the prediction of propagation. Therefore, a SAR-based continuous monitoring system might help building more robust pavement and infrastructure monitoring and reduces/prioritizes routine vehicle-based inspection trips and associated monitoring cost. Considering most agencies perform routine inspections on pavement and infrastructure elements such as bridges in different cycles (1-3 years), monthly monitoring with satellite imagery is expected to contribute to the routine monitoring efforts by providing more frequent data in network-level [7].