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PRIMENA SAR INTEREFEROMETRIJE ZA ODREĐIVANJE KOSEIZMIČKIH DEFORMACIJA: TRENDOVI I DOSTIGNUĆA

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Ključne reči: DInSAR, PSInSAR, zemljotres, rased, komponente kretanja

U radu je prikazan pregled razvoja, metodologije i primene radara sa sintetičkom blendom (*eng: Synthethic Aperture Radar - SAR*), interferometrijskog SAR-a (InSAR) i pratećih tehnika, za potrebe upotrebe InSAR-a prilikom proučavanja posledica zemljotresa. Zemljotresi su jedan od najčešćih i najdestruktivnijih geoloških hazarda, koji mogu da generišu kako direktnu tako i indirektnu značajnu (ekonomsku) štetu i ljudske žrtve. Štete od zemljotresa su često tolike, da nije moguće fizički dopreti do pogođenih područja i ugroženog stanovništva. U takvim okolnostima, upotreba daljinske detekcije, konkretno upotreba i primena SAR snimaka, odnosno InSAR-a, može biti od velikog značaja. Sam koncept SAR-a, prvi put je prikazao Carl Wiley 1951. godine, da bi naučnoj javnosti postao jasan značaj upotrebe SAR-a u geonaukama tek 1978. godine, kada je i lansirana prva SAR misija (SeaSat-SAR). Iako je SeaSat satelit u orbiti bio operativan samo 105 dana, pružio je značajane podatke, koji su kasnije bili primenjivani u geonaukama, uz podjednako značajnu primenu u inženjerstvu. U godinama koje su sledile, omasovljen je razvoj i primena SAR satelitskih misija, što je praćeno razvojem tehnika obrade prikupljenih podataka, sve ovo je doprinelo da se značajno proširi područje njihove primene. Naročito je unapređena SAR interferometrija, koja se prvi put pominje u Nature časopisu 1993. godine i izaziva veliku pažnju naučne javnosti.

Osim za brzo reagovanje u kriznim situacijama, SAR interferometrija se može primeniti za proučavanje seizmički aktivnih raseda i monitoringa njihove dinamike. Da bi primena SAR snimaka bila moguća u tom slučaju, neophodno je da zemljotres bude magnitude > 5 i da su registrovana značajnija pomeranja duž raseda. Razvoj SAR interferometrije se odvijao u dva pravca: upotreba i primena diferencijalne InSAR (DInSAR) i InSAR sa fazno stabilnim radarskim metama (PSInSAR). Obe tehnike imaju za cilj praćenje pomeranja, s tim da je u slučaju PSInSAR tehnike moguće vršiti monitoring kretanja, ali i preciznije određivanje pomeranja/rušenja posmatranih objekata u slučaju zemljotresa. Za definisanje koseizmičkih deformacija terena najpre se koristi DInSAR tehnika. Pomeranja terena se mogu determinisati korišćenjem odgovarajućih parova snimaka (pre i nakon zemljotresa). Sam razvoj tehnike ide u pravcu proračuna deformacija u pravcu pogleda senzora (eng. *Line of sight* - LOS), kada je neophodno analizirati interferograme pre i nakon zemljotresa iz jedne putanje leta senzora. Upotrebom parova snimaka iz dva režima leta (uzlaznog i silaznog) moguće je računati pomeranja u vertikalnom i horizontalnom pravcu. Ukoliko se i horizontalni pravac razloži na pravce istok-zapad i sever-jug, tada je moguće sprovesti 3D analizu koseizmičkih deformacija terena.

Kako je od sveopšteg interesa razvoj, ali i primena InSAR tehnika, tako su, zahvaljujući Kopernikus programu ESA-a, SAR snimci postali besplatno dostupni i široj zainteresovanoj stručnoj i naučnoj javnosti, ali i programski paketi u kojima je moguće izvršiti njihovu obradu. Njihova glavna prednost je kontinuirano snimanje površine Zemlje i besplatna dostupnost, što rezultuje konstantnim unapređivanjem tehnike, ali i njihove primene. Ovaj rad ima za cilj predstavljanje metodologije kroz sveobuhvatnu analizu tri zemljotresa i to od pristupanja dostupnim SAR snimcima, njihovoj obradi u SNAP programskom okruženju, uz detaljan prikaz šeme obrade i određivanje deformacija u LOS pravcu, razlaganje deformacija iz LOS pravca na komponente, kao i korelaciju i dopunjavanje sa drugim javno dostupnim podacima. Glavni pravac razvoja SAR se ogleda u javnoj dostupnosti snimaka i njihovoj masovnoj primeni. Umrežavanje istraživača i razmena podataka, rezultata i informacija, dovela je do formiranja globalne baze podataka kojoj je moguće lako pristupiti, na osnovu čijih podataka je moguće sprovođenje daljih istraživanja ili organizacija pomoći relativno brzo i jednostavno, u zavisnosti od situacije i iskazanih potreba u datom trenutku, neposredno nakon zemljotresa.

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SAR INTERFEROMETRY FOR COSEISMIC DISPLACEMENT DETERMINATION: TRENDS AND ACHIEVEMENTS

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Key words: DInSAR, PSInSAR, earthquake, fault, displacement component

The paper presents an overview of the development, methodology and application of Synthetic Aperture Radar (SAR), interferometric SAR (InSAR) and related techniques for the study of earthquake consequences. Earthquakes are one of the most common and destructive geological hazards, which can generate both, direct and indirect, significant (economic) damage and human casualties. The damage from earthquakes is often so great that it is not possible to physically reach the affected areas and the endangered population. In such circumstances, the use of remote sensing, specifically the use and application of SAR images, or InSAR, may be of great importance. The concept of SAR was first introduced by Carl Wiley in 1951. The scientific public understood the importance of using SAR in geosciences in 1978, when the first SAR mission (SeaSat-SAR) was launched. Although the SeaSat satellite was in orbit for only 105 days, it provided significant data, which were later applied in geosciences, with equally significant application in engineering. In the following years, the development and application of SAR, and thus the processing of collected data, was expanded, and InSAR was especially improved. InSAR was first mentioned in Nature magazine in 1993 and attracted great attention of the scientific community.

In addition to quick responding in crisis situations, SAR interferometry can be used to study seismically active faults and to monitor their dynamics. For that application of SAR images, the earthquake magnitude should be > 5, and existence of significant displacement along the fault is needed. The development of SAR interferometry took place in two directions: Differential Interferometric Synthetic Aperture Radar (DInSAR) and Persistent Scatterers Interferometry Synthetic Aperture Radar (PSInSAR). Both techniques aim to detect displacement, with the proviso that in the case of the PSInSAR technique it is possible to monitor displacement, but also more accurately determine the displacement/demolition of observed infrastructures. DInSAR should be the first choice for determination of coseismic deformations of the terrain, using appropriate pairs of images (before and after the earthquake). The development of the technique itself goes in the direction of calculating the deformations in the line of sight (LOS), when it is necessary to analyze the interferograms before and after the earthquake from one flight path of the sensor. By using pairs of images from two flight modes (ascending and descending), it is possible to calculate displacements in the vertical and horizontal directions. If the horizontal displacement is decomposed into E-W and N-S directions, it is possible to conduct a 3D analysis of coseismic deformations.

As it is of general interest to develop and apply InSAR techniques, thanks to the ESA Copernicus program, SAR scans have become available free of charge to the wider interested professional and scientific public, as well as software packages in which processing is possible. Their main advantage is the continuous imaging of the Earth's surface and free availability, which results in the constant improvement of technology, but also the expansion of their application. This paper aims to present the methodology through a comprehensive analysis of three earthquakes, from access to available SAR images, their processing in SNAP software environment, with a detailed presentation of the processing scheme and determination of deformations in the LOS direction, decomposition of deformations from LOS direction into components and correlation and supplementing with other publicly available data. The main direction of SAR development is reflected in the public availability of recordings and their mass application. Networking and exchange of data, results and information has led to the creation of a global database, which can be easily accessed and based on which further research or assistance can be conducted relatively quickly and easily depending on the situation, immediately after the earthquake event.

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