Orbital grain size mapping from Sentinel 2 images

Caractérisation de la taille de sédiments à partir d'images de Sentinel 2

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RÉSUMÉ

L'utilisation de la télédétection est fondamentale pour le monitorage et la gestion des systèmes fluviaux. Pour mieux comprendre les processus fluviaux, une des variables clé est la taille de sédiments du lit et son patron de changement le long des rivières et dans le temps. En fonction des caractéristiques de surface, la lumière du soleil est réfléchie par le sol en fonction de nombreux paramètres tels que la rugosité, liée à la géométrie et à la forme des grains. Cet article étudie les potentialités des données multi-spectrales Sentinel 2 pour l'extraction de la granulométrie des bancs de sédiments. La méthodologie utilise des images UAS acquises à faible altitude pour mesurer la taille de grains et la corréler aux valeurs de rayonnement des images Sentinel 2. Les résultats montrent qu'il est possible de distinguer entre classes de sédiments (du gravier fin aux galets grossiers) à partir des données de Sentinel 2. La région du SWIR est la plus sensible, capable d'expliquer environ 70% de la variance. Le modèle a ensuite été appliqué sur environ 500 km du Po en Italie. Le patron de réduction de la taille de sédiments obtenu est comparable aux valeurs publiées dans la littérature et semble cohérent avec la présence des principaux affluents et des infrastructures existantes le long du fleuve. Cette méthode représente potentiellement une avancée majeure pour la caractérisation des habitats et des processus fluviaux actuels des grands systèmes fluviaux, grâce aux caractéristiques des données de Sentinel 2, disponibles gratuitement dans le monde entier tous les 5 jours environ. La méthodologie proposée permettra une cartographie objective et rapide de la taille de sédiments, facilement applicable à d'autres grandes rivières.

ABSTRACT

Remote Sensing technology is crucial for comprehensive river management capable of monitoring the hydromorphological features of entire river systems. To better understand fluvial processes, a key variable is the bed material grain size distribution and its pattern of change along rivers and over time. Depending on surface characteristics, sunlight reflected from the soil changes as function of many parameters such us surface roughness, linked to geometry and shape of single grains. Building on this evidence, the paper investigates the potential of Sentinel 2 multispectral data for grain size mapping of exposed river sediment bars. The methodology uses near ground UAS imagery in order to correlate local grain sizes to Sentinel 2 radiance values. Results show that it is possible to discriminate broad classes of sediment (from fine gravel to coarse cobbles) from Sentinel 2 data. The most sensitive band capable alone to explain around 70% of the variance is in the SWIR region. The methodology has then been applied on about 500 km of the major Italian river, the Po river. The resulting fining pattern is comparable to others reported in literature and is coherently linked with main tributaries and river infrastructures existing along its course. This method represents potentially a major advance in our current ability to characterize fluvial habitats and processes along major river systems, thanks to the characteristics of Sentinel 2 data, free available worldwide with a time frequency of about 5 days. The proposed methodology opens to the possibility to routinely map grain size classes along any large river areas thus generating broad perspectives for future fluvial survey practices.

KEYWORDS

Grain size mapping, fluvial geomorphology, Sentinel 2, UAS imagery

1 INTRODUCTION

A key variable to delineate and characterise river geomorphic units and to better understand fluvial processes is bed grain size distribution and its pattern of change along rivers and over time. Sediment dimensions are important for mechanical and fluid dynamic properties of sediments, regulating channel morphology, hydraulics and fluvial ecosystems functioning. Field based approaches are still dominating in river surveys and their prerequisites limit their application at the network scale and may fail in guaranteeing an objective and repeatable monitoring assessment (Bizzi et al., 2015). In this context, in the last two decades, remote sensing (RS) technology has opened up new possibilities for river science, providing continuous data over entire catchments, allowing for a comprehensive river management. Recently the European Spatial Agency (ESA) has launched a new family of satellite missions, called Sentinels, which supply accurate, timely and easily accessible information, available worldwide, providing an unparalleled amount of free data to be investigated.
This paper investigates the potential of Sentinel 2 multispectral data in discriminating broad classes of sediment (from fine gravel to coarse cobbles) of exposed river sediment bars. We know that, depending on surface characteristics, the sunlight reflected from the soil changes as function of many parameters such us surface roughness and previous studies have shown that there is a correlation between particles and spectral signature of a sediment (Black et al., 2014, Carbonneau et al., 2004). Building on this evidence, we further investigated this relationship using satellite multispectral information.

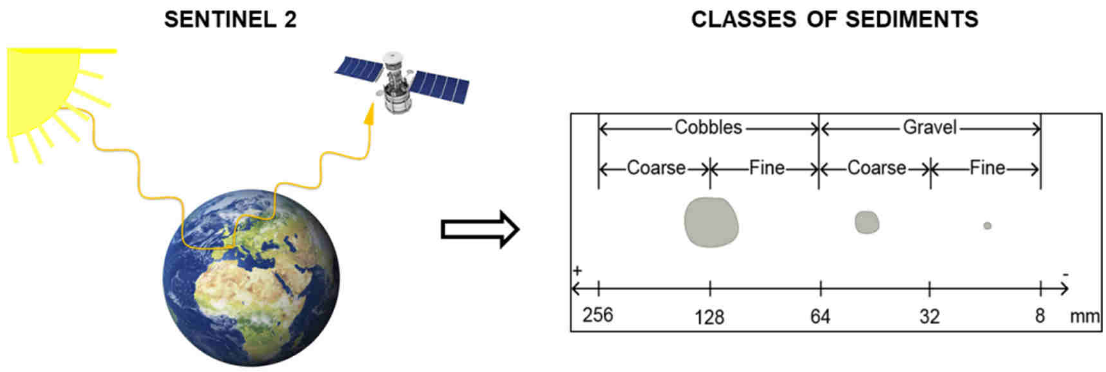

Figure 1. Schematic representation of the objective of the study: investigate the potential of Sentinel 2 multispectral data in discriminating broad classes of sediment of exposed river sediment bars.

2 METHODOLOGY

The proposed methodology uses two innovative remote sensed technologies for grain size mapping: satellite multispectral imagery and Unmanned Aerial Systems (sUAS) imagery. The former provides the spectral information, the latter is useful to build ground truth grain size dataset, needed for validation. For each selected site, sUAS images were acquired on large exposed sediment bars, vegetation-free and homogeneous over several meters. From each acquired image, grain size percentiles (D50 and D84) were then extracted by photosieving technique.
Sentinel 2 images were simultaneously downloaded from Copernicus services data hub by selecting the specific area of interest and the time of acquisition (close to the sUAS images acquisition). Sentinel 2 data provide reflectance values in 13 different bands from the visible to the SWIR (short-wavelength infrared) region. Atmospheric correction was applied using the ESA software Sen2Cor. In order to study the existing correlation between grain size percentiles and multispectral data, a functional model (linear regression model) was identified.

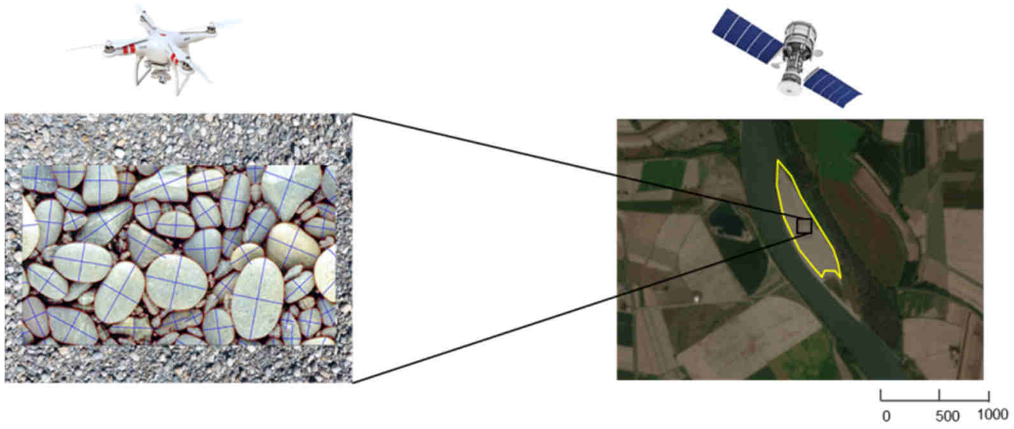

Figure 2. From local to global: grain size mapping at large scale. sUAS imagery useful for grain size percentiles measurement and Sentinel 2 imagery which provides the spectral information.

We then applied the model to predict grain size pattern along about 500 km of the largest Italian river, the Po river, on a total of 109 sediment bars. The purpose was to study if the predicted grain size pattern from upstream to downstream follows specific patterns observed in literature.

3 RESULTS AND CONCLUSIONS

Results show that the SWIR region is the most significant explaining a total of about 70% of the variance for the D50 percentile prediction, with an accuracy of about 12 mm. The model calibrated on reflectance values of the 9 bands available at 20 m resolution after the atmospheric correction displays encouraging results: the coefficient of multiple determination for the D50 percentile model is R^2=0,95 and the corresponding accuracy is about 6 mm.
Results of the model application on the selected sediment bars along the Po river, point out a meaningful relationship between rate of change of grain size and downstream distance: the diminution rate (-0,0057 mm/km) and R^2 (0,58) of the negative exponential model are comparable with values already reported in literature and the resulting fining pattern is coherently linked with main tributaries and river infrastructures existing along the river length investigated.
As a conclusion, results show that the relation between reflectance values and surface grain size percentiles is significant, at least for the surveyed area. By using Sentinel 2 data it seems possible to discriminate classes of sediment from fine gravel to coarse cobbles, with an accuracy comparable with errors already reported in literature (Black et al., 2014). Moreover, the combination of satellite and sUAS remote sensed technologies introduces a new, objective, efficient and repeatable methodology for grain size mapping in large rivers, opening up broad perspectives for future fluvial survey practices. Further studies are required to better understand physical explanations behind observed phenomena by testing the methodology on other large rivers different in geology, lithology and geographic settings.

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