Analysis of Satellite Images for the Purpose of Tracking Deforestation in West Africa

Jan Drabek
j.drabek@student.vu.nl
Department of Computer Science, Vrije Universiteit Amsterdam
Amsterdam, The Netherlands

ABSTRACT

The illegal tree-cutting is a severe problem negatively affecting many rural communities in West Africa. The sparse trees in African savannas have tremendous influence on the local biome, biodiversity richness, water supply, and provide great agricultural value to the people. Fighting the small organised groups stealing trees proved to be difficult without hard evidence rooted in data. Reporting the incidents by the inhabitants proves to be ineffective, disorganised and sometimes even dangerous. Applying satellite image analysis of the vegetation has the potential to provide the authorities with concrete timely data. This paper presents a design for research which focuses on how public satellite images can be used to track the illegal tree-cutting incidents in the region of Mali West Africa.

KEYWORDS

deforestation, satellite imagery, remote sensing, image processing, tree cutting

1 INTRODUCTION

Tree theft is a real problem many people face in rural drylands in West Africa. Trees are being stolen from private lands which can dramatically influence the lives of the rightful owners in very negative ways. People in countries like Mali have very little physical possessions, the few trees are like savings in bank accounts for them, in which they invest a lot of time and effort [4].

Rural communities in the southern part of Mali, which is the region on focus of this paper, one of the most prevailing biome are the savannas. Trees have significant influence on the closest surroundings, influencing both the local fauna and flora [16]. Changes in forests and tree cover can greatly affect the ecosystem in terms of climate regulation, biodiversity richness, water supplies and carbon storage [6]. These crimes are a big obstacle in any regreening efforts of the drylands, which promise to transform the degraded landscapes into productive areas with sustainable land management practices [15].

Trees are disappearing from privately held properties of the local people because of tree theft conducted by small organised groups. For the local forestry services it is difficult to fight this crime because of the large ground area needed to be covered.

Remote sensing and in particular satellite images analysis is a promising complementary tool to help the authorities fight these crimes. The publicly available free imagery from satellites provides high resolution view of the Earth on a periodical basis. Remote sensing can be done utilizing data from different kinds either airborne or spaceborne sensors. Furthermore powerful signal processing methods are being developed which allow exploiting this information even in greater detail [2].

The combination of the vast amount of satellite data with modern data processing techniques, including machine learning, has the potential of bringing tremendous value to help to identify tree theft in West African countries.

2 PROBLEM STATEMENT

The lack of evidence through the absence of hard quantitative data makes fighting the free cutting very difficult. It is infeasible, both from time and costs perspective, for the authorities to track the incidents only with human force, even more so, preventing the tree cutting from happening in general. For the local people it can be dangerous trying to stop the theft form happening or even simply reporting these organised groups responsible for the crimes.

A cost effective system, that would provide quantitative data about tree cutting to the authorities, is needed. Public satellite images appear to be a data source worth investigating for this purpose. Combining the satellite images with other types of information might be necessary in order to achieve a reasonable level of accuracy.

3 RESEARCH QUESTION

With consideration to the goal and challenges presented earlier, the research is trying to answer the following question:
What is a promising approach for analyzing public satellite images to identify tree-loss in West Africa?
In order to answer the main research question, several sub-research questions have to be addressed as well:

(1) Sub-RQ1: What other data in addition to the satellite images can be used to improve the accuracy of the potential system?
(2) Sub-RQ2: Considering both object detection approach and pixel based analysis, which method is better suited for the introduced problem?

4 BACKGROUND

In this section a deeper look into the existing solutions on utilizing remote sensing data to capture valuable insights is taken. First of all, the remote sensing field of study is described in general. After that, the focus will be specifically on the satellite imagery analysis. Finally some existing use cases on leveraging satellite imagery will be introduced.

4.1 Remote sensing

In essence, remote sensing is the acquisition of some properties about the object or phenomena of interest, without having the measuring device in a direct contact with the subject [10].

Remote sensing sensors can be classified as either active or passive. Those sensors, which react to the natural radiation emitted or reflected from the observed surface (e.g. reflected from Earth) are called passive, an example would be digital camera. The active sensors produce their own electromagnetic radiation in order to illuminate the surface by this artificially created radiation. A digital camera with flash could be considered an example of an active sensor.

There are several major parameters which define the characteristics of the captured data. *Spatial resolution*, is a measure of the smallest object that can be resolved by the sensor. Usually expressed in meters or centimetres per pixel. *Spectral resolution*, the spectral bandwidth with which the image is taken, meaning the range of the captured wavelengths. *Temporal resolution*, denoting the time interval between individual observations of the same area of interest. *Radiometric intensity*, which is the number of discrete values of brightness the sensor is capable to distinguish. [14]

For purpose of this paper it is also important to introduce 2 different categories of remote sensing systems from the perspective of where the sensors are: airborne systems and spaceborne systems.

Airborne systems, which include plains and unmanned aircraft systems (UAS) with attached sensors, operate on relatively low altitude above the Earth's surface. Being closer to the observed area allows for higher spatial resolution and use of sensors which can not operate from the spaceborne systems. One of such sensors is LiDAR, which can create a 3D map of the scanned surface and thus providing the height information about the examined objects. This method of remote sensing is useful only on local basis. In case of large areas or on the global scale using air-crafts becomes unpractical. [11]

Spaceborne systems offer much larger aerial coverage than airborne systems. It is mostly sensors attached to satellites or spacecrafts capturing the surface of the whole planet Earth. Some of the satellites are operated by governments which provide the captured data freely without charge. One of such satellites is the Sentinel-2 operated by the European Space Association (ESA) launched in 2015 as part of the European Copernicus program [8]. The Sentinel-2 project is a twin satellite system which offers a global coverage of the Earth with 5 day temporal resolution (on the Ecuador). The satellites carry an optical multi-spectral imager (MSI) payload that captures 13 spectral bands: 4 bands at 10m, 6 bands at 20m and 3 bands at 60m spatial resolution [12]. At the time of working on this paper, this is the best spatial resolution out of all the publicly available satellite imagery sources, right in front of the popular Landsat project of the USGS/NASA initiative with spatial resolution of 30m [9]. The high spatial resolution of the Sentinel-2 satellite, was the reason why the imagery form this project is used as the main data-source in this paper. There are privately operated satellites which offer spatial resolution around 0.6m, unfortunately the data produced is not publicly available [1].

4.2 Satellite imagery analysis

What is important to note, especially in the case of analysing satellite imagery is how the satellite data is presented. Light can be either reflected from the object surface, it can be absorbed, scattered or refracted. Optical sensors measure the quantity of light reflected by the surface observed in a given range of wavelengths. If all of the wavelengths reflected from the surface are observed together, we speak of a panchromatic image (all colours are included) [5]. In other cases, wavelengths can be divided by into multiple bands, each of the bands having own wavelength range. This separation into multiple bands produces so called multi-spectral images [5]. Various materials have differ in reflectance of different wavelengths, it is possible to show how much of the electromagnetic radiance is reflected from that material across the wavelength spectrum, this is called spectral signature. For example vegetation has strong response to near infrared wavelengths and in this band can be easily differentiated from other types of materials like water [5]. Different materials can be identified by the reflectance intensity in different wavelength bands, this can be amplified by various combinations of bands to highlight certain features in the image. This feature is used to classify what does each individual pixel in the image represent, like a tree.

4.3 Use cases of satellite image analysis

In the domain of vegetation analysis from satellite imagery, there have been multiple types of different applications developed. They can be categorized based on the unit of analysis they examine.

One category is identifying individual trees in the imagery. Various approaches have been developed on detecting individual trees from remote sensing data, however these methods usually require very high spatial resolution and often specialised sensors like LiDAR for height detection as an additional source of data. Methods used in these experiments, like edge detection and locating local maxima of the pixel values are only usable with very high resolution satellite or airborne imagery. The spatial resolution of the input images is usually 0.6m or better. The very high resolution is necessary because the shapes of the trees need to be clearly recognisable in order to conduct object detection. Often supervised learning algorithms are utilized and thus fairly large sets of training data are needed. In addition the applications often focus only on identifying trees of one species that can be easily detected and are constrained with a specific pattern in how the trees are planted. The paper on counting of palm trees on plantations is an example of such restricted context application [1]. In order to identify individual trees, human aided systems are developed. The paper on identifying trees for wild-forest-fires simulations [3]. This paper describes an application that allows the user to guide the automatic detection of trees from satellite imagery and spatial vegetation data for the purpose of building virtual reconstructions of the world for wild-fire simulations. The system relies heavily on the user, during the execution of the algorithm user has to take action and tune all of the important parameters by his/her own judgement in order to get the best result as a trial and error process.

The other category of use cases takes a different approach than the object detection described earlier. The images are analyzed on a pixel basis instead of trying to identify whole trees. By doing that an area is identified pixel by pixel where the material is categorised usually based on the spectral signature of that material. This approach is more suitable for lower resolution images like the one from Sentinel-2, Landsat and other public satellites. This way, applications on crop species classification and in the forestry domain on estimation of the forests gain/loss and tree species classification [8, 13].

For the purpose of tracking tree cutting in West Africa utilizing the Sentinel-2 imagery, both introduced approaches are carefully examined.

5 METHODOLOGY

In order to answer the the established research question and come up with a appropriate solution, the context and the interests of the stakeholders has to be understood carefully. This will achieved by being in close contact with the research team right in Mali, who can mediate our communication with the villagers, local authorities and other local experts. The tight connection to all of the stakeholders is important not only in the beginning phase of the project but will be maintained throughout the whole process of system design, development and evaluation. When designing the system, various possible additional data sources will be taken into account in order to constraint the context and improve the accuracy of the system. In the next phase, both object detection and pixel analysis based approaches will be examined in order to assure the best possible design. In case object detection shows to be more suitable method, effort has to be put into building a large enough training data set for the supervised-learning algorithm. In any case, satellite images will have to be pre-processed in an appropriate way to highlight the areas of interests (trees and forests) in order to make any further processing more effective. In order to identify tree-cutting incidents, images from different time-points have to be compared. During the design, it has to be decided at which point will this comparison be conducted. At any point where multiple promising methods will be found, their expected performance will be assessed and compared to ensure that the most appropriate approach can be taken. The potential system will be evaluated and tested first in a simulated lab environment and afterwards with the team onsite in Mali. The intermediate evaluation will be conducted on regular basis to ensure the project is not deviating from the real use-case. Finally, the results have to be presented in a clear manner and evaluated for accuracy. Throughout the design and development phase, sustainability has to be kept in mind. The solution has to be cost effective, timely in order to identify the incidents soon enough that some measures can be taken and maintainable. Questions like "How much does it cost running the system?", "How to change the data source if the current one is shut down?" and "How can the product be expanded to other regions?", need to be answered in the final project in order to launch it for production in Mali.

In the rest of this section, the overall methodology of the design is introduced. The general structure of this study follows the design science research [7]. Figure 1 represents an overview of the design and implementation of the system introduced in this paper. The middle segment represents the design of the solution and iterative evaluation at every major step in the design process. The solution is constantly influenced by the environment and context that puts constraints on the desired system, that is symbolised by the relevance cycle. The rigor cycle represents the influence of the existing theories and knowledge. It is important to reference to existing theories in order to ensure scientific importance instead of designing system based on well-known methods.

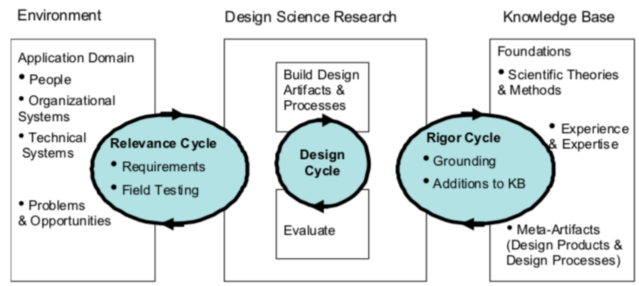

Figure 1: Design Science Research Cycle, from Hevner's paper [7]

6 PROJECT PLANNING

It is important that the study will be finished on time without any of the major milestones and steps being omitted. Figure 2 attached to this document presents a project plan for the whole period designated for the work on the thesis described in this design paper.

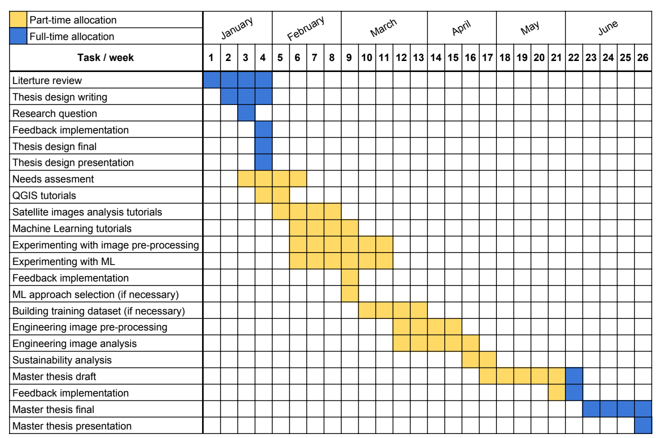

Figure 2: Project time plan

REFERENCES

[1] Emad Ali Al-helaly and Noor Ali Al-Helaly. 2018. A Count of Palm Trees from Satellite Image. arXiv:arXiv:1805.11433

[2] Ursula C. Benz, Peter Hofmann, Gregor Willhauck, Iris Lingenfelder, and Markus Heynen. 2004. Multi-resolution , object-oriented fuzzy analysis of remote sensing data for GIS-ready information.

[3] David T. Brown, Roger V. Hoang, Matthew R. Sgambati, and Frederick C. Harris. 2009. An Application for Tree Detection Using Satellite Imagery and Vegetation Data. In *SEDE*.

[4] Robert Chambers and Melissa Leach. 1989. Trees as savings and security for the rural poor. *World Development* 17, 3 (1989), 329–342.

[5] Emilio Chuvieco (Ed.). 2008. *Earth Observation of Global Change*. Springer Netherlands. https://doi.org/10.1007/978-1-4020-6358-9

[6] J. A. Foley. 2005. Global Consequences of Land Use. *Science* 309, 5734 (jul 2005), 570–574. https://doi.org/10.1126/science.1111772

[7] Alan R. Hevner. 2007. A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems* 19, 4 (2007).

[8] Markus Immitzer, Francesco Vuolo, and Clement Atzberger. 2016. First Experience with Sentinel-2 Data for Crop and Tree Species Classifications in Central Europe. *Remote Sensing* 8, 3 (feb 2016), 166. https://doi.org/10.3390/rs8030166

[9] James R. Irons, John L. Dwyer, and Julia A. Barsi. 2012. The next Landsat satellite: The Landsat Data Continuity Mission. *Remote Sensing of Environment* 122 (2012), 11 – 21. https://doi.org/10.1016/j.rse.2011.08.026 Landsat Legacy Special Issue.

[10] Siamak Khorram, Stacy A.C. Nelson, Frank H. Koch, and Cynthia F. van der Wiele. 2012. *Remote Sensing*. Springer US. https://doi.org/10.1007/978-1-4614-3103-9

[11] Andrea S. Laliberte, Craig Winters, and Albert Rango. 2011. UAS remote sensing missions for rangeland applications. *Geocarto International* 26, 2 (2011), 141–156. https://doi.org/10.1080/10106049.2010.534557 arXiv:https://doi.org/10.1080/10106049.2010.534557

[12] ZbynÄŽk MalenovskÃ¡, Helmut Rott, Josef Cihlar, Michael E. Schaepman, Glenda GarcÃŋa-Santos, Richard Fernandes, and Michael Berger. 2012. Sentinels for science: Potential of Sentinel-1, -2, and -3 missions for scientific observations of ocean, cryosphere, and land. *Remote Sensing of Environment* 120 (2012), 91 – 101. https://doi.org/10.1016/j.rse.2011.09.026 The Sentinel Missions - New Opportunities for Science.

[13] Marc T. Mayes, John F. Mustard, and Jerry M. Melillo. 2015. Forest cover change in Miombo Woodlands: modeling land cover of African dry tropical forests with linear spectral mixture analysis. *Remote Sensing of Environment* 165 (2015), 203 – 215. https://doi.org/10.1016/j.rse.2015.05.006

[14] Rangnath R. Navalgund. 2002. Remote sensing. *Resonance* 7, 1 (01 Jan 2002), 37–46. https://doi.org/10.1007/BF02836169

[15] Chris Reij and R Winterbottom. 2015. Scaling up regreening: Six steps to success. *World Resources Institute, Washington DC, United States* (2015), 66.

[16] Abasse Tougiani, Chaibou Guero, and Tony Rinaudo. 2009. Community mobilisation for improved livelihoods through tree crop management in Niger. *GeoJournal* 74, 5 (2009), 377.