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Combining automatic and manual image analysis in a web-mapping application for collaborative conflict damage assessment

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ABSTRACT

Remote sensing is increasingly being used by non-profit organizations and international initiatives to localize and document combat impacts such as conflict damage. Most of the practical applications rely on labor-intensive and time-consuming manual image analysis. Even when using crowdsourcing or volunteer networks, the workload can quickly become challenging when larger areas have to be monitored over longer time periods. In this paper, we propose an approach that combines automatic change detection methods with collaborative mapping in a web application for conflict damage assessment in Darfur, Sudan. Settlement areas are automatically detected and searched for destructed dwelling structures by geographic object-based image analysis (GEOBIA). The web application prioritizes these areas based on the detected degree of destruction to guide human analysts to the most important locations. In a user experiment with 30 participants we evaluated the performance of volunteers with and without the automatic prioritization and investigated their mapping sequences. Participants who were guided by the prioritization detected 70.7% more target objects than participants mapping without guidance, who invested parts of their mapping time in examining locations that show little to no destruction.

1. Introduction

1.1. Motivation

The use of satellite-based remote sensing for the monitoring and documentation of violent conflicts has strongly increased in recent years. The growing availability of satellite imagery enables visual access to areas that are hard to reach or too insecure to be covered by ground-based monitoring (Witmer, 2015; Wolfinbarger & Wyndham, 2011). Non-profit organizations and international initiatives are increasingly using these opportunities, e.g., to localize and document conflict damage, to corroborate on-the-ground reports on atrocities or even to report signs of likely upcoming hostilities (see, for example, American Association for the Advancement of Science, 2014b; Amnesty International, 2016; Harvard Humanitarian Initiative, 2012; United Nations Institute for Training and Research, 2011). The main goal often is to put pressure on involved actors through increasing public awareness (Livingston, 2015) and to eventually influence their behavior. In addition, remote sensing has also received attention as an investigatory tool by international judicial bodies such as the International Court of Justice (ICJ) or the International Criminal Court (ICC, see (Wolfinbarger, 2016). Another important application of remote sensing in conflicts is the monitoring of cultural heritage. The destruction of heritage sites due to, e.g., deliberate attacks or looting is a recurring issue during violent conflicts or phases of political instability (Kila, 2016). Satellite imagery has been used to investigate and document the loss of cultural heritage or to assess threats to archaeological sites in a number of countries (see, e.g., American Association for the Advancement of Science, 2014a; Banks, Fradley, Schiettecatte, & Zerbini, 2017; Bewley et al., 2015).

Most of the current practical applications of remote sensing in conflicts rely on manual image analysis by trained experts. This analysis is labor-intensive and time-consuming, especially when analyst resources are limited (Meier, 2011b). One strategy to cope with the immense workload is to distribute it among a larger number of volunteers in crowdsourcing applications, some of which are described in the following section.

However, the manual analysis of remote sensing images remains a labor-intensive task, especially when larger areas have to be monitored over longer time periods or when analysis tasks are more complex (e.g., requiring analysts to compare images from two dates). Even for volunteer networks, the workload can be challenging, not least because only a certain percentage of volunteers is available at any given time (Meier, 2011b).

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Another approach is to use automatic image processing on remote sensing data to analyze conflict areas. Automatic classification and change-detection methods, for example, have been developed for finding and analyzing combat impacts such as damaged and destroyed building structures (Pagot & Pesaresi, 2008; Sulik & Edwards, 2010), direct and indirect environmental effects of conflicts (Abuelgasim, Ross, Gopal, & Woodcock, 1999; Nackoney et al., 2014), or population displacement and refugee camp evolution (Lang, Tiede, Hölbling, Füreder, & Zeil, 2010).

An important concern in this context is how to effectively and responsibly integrate such methods into workflows of conflict monitoring and analysis. The documentation of conflict impacts, and especially of possible human rights violations, is a precarious field. There is broad consent that reported results in this field should be of highest possible accuracy (Orentlichter, 2016), not least because of the severe allegations they might lead to and the possible consequence of raising false charges (Blitt, 2004; Groome, 2011). Due to the uncertainty of automatic image analysis, the results should not be used as unmediated evidence in this context. Nonetheless, they can support processes of human rights reporting especially with regard to workload and efficiency in monitoring of larger areas. Several authors have argued for developing approaches to combine automatic image analysis with collaborative mapping for the investigation of conflict areas (see, for example, Meier, 2011b; Witmer, 2015).

In this paper we present an approach for such a hybrid detection method to increase the efficiency of manual image interpretation in conflict damage assessment. The proposed framework combines automatic image analysis with a microtasking approach for collaborative mapping that is implemented as a web application. We apply geographic object-based image analysis (GEOBIA) to automatically determine the degree of destruction in a conflict area. Based on this estimation, the web application coordinates the analyses of subsets by guiding analysts to those areas that contain most important information. We conduct a user experiment to investigate the mapping sequence and performance of volunteers and to compare the investigation with and without guidance through automatic prioritization of subsets.

1.2. Background

The advent of new information and communication technologies has had a huge impact on the humanitarian and human rights sectors. The workflows of NGOs have been changed in several facets, e.g. the collection and processing of information, the way humanitarian response is organized, and the array of involved actors (Meier, 2011b). For example, volunteers can support relief operations after disasters by issuing situation reports and help requests via SMS, social media, email and other, or by mapping affected areas based on remote sensing images. Prominent examples include the mapping campaign in the aftermath of the Haiti earthquake in 2010 (Heinzelman & Waters, 2010; Hester, Shaw, & Biewald, 2010), the efforts by the Humanitarian OpenStreetMap Team (HOT) after the earthquake in Nepal in 2015 (Poiani, dos Santos Rocha, Degrossi, & de Albuquerque, 2016) and many others. The Missing Maps project even engages volunteers in the preventative mapping of vulnerable, sparsely mapped areas in order to have high quality spatial data in place immediately when a disaster strikes (Herfort, Eckle, & de Albuquerque, 2016).

This increasing involvement of volunteers can also be observed in the field of fact-finding for human rights and international law. Traditionally the practice of gathering testimony through interviews of witnesses and victims is the main tool to gather information on human rights issues (see, for example, UN Commission of Inquiry on the Syrian Arab Republic, 2016), but new techniques exploiting, e.g., social media, Geographic Information Systems (GIS) and remote sensing are increasingly being used (Alston & Knuckey, 2016; Aronson, 2016).

One of the earliest examples is the Ushahidi platform, which was developed in 2008 to document human rights violations during the post-election violence in Kenya. It allowed witnesses and victims to report incidents via web-form, email or SMS. The reports were combined with additional information to build a crisis map that was updated in near-real time (Okolloh, 2009). The Ushahidi platform has since then been used in a large number of deployments in various scenarios such as the Libya Crisis Map 2011 (Burns, 2014).

An important notion of this development is that it is not merely about enlarging the workforce through the recruitment of volunteers or increasing efficiency by use of new technologies. It also opens up the documentation process to ordinary individuals including those directly impacted by conflicts, thus turning subjects into agents (Land, 2016).

A common strategy to involve volunteers in conflict documentation is collaborative mapping in satellite images using a microtasking approach. Here, the images are divided into a regular grid of smaller subsets that can be investigated individually (Barrington et al., 2011). Different conflict mapping projects have engaged in using volunteers for mapping conflict related issues such as emerging of refugee shelters in Somalia (Meier, 2011a). Amnesty International applied a crowdsourcing approach to map remote settlements in Darfur (Amnesty International, 2017a) and, in a follow-up project, monitor changes in those settlements (Amnesty International, 2017b).

The volunteer projects and communities are usually not focused only on conflict but engage in all kinds of crises (e.g., natural disasters). They differ in terms of size and their organizational form, ranging from networks of trained volunteers with organizing principles such as task sharing, a code of conduct or specific activation criteria (e.g., the Standby Task Force[1] or the GISCorps[2]) to open microtasking and crowdsourcing platforms where everyone can contribute on an ad hoc basis (e.g., Tomnod[3] or the HOT Tasking Manager[4]).

Volunteer networks have also partnered with microtasking platforms and satellite imagery vendors. In these examples, the former mobilized the volunteer workforce while the ladder provided the technological platform for the collaborative mapping and the satellite imagery to conduct the analysis on (Meier, 2013).

An important question for such platforms is how to divide, select, and prioritize tasks such that individual volunteers can efficiently contribute to the overall goal. Previous research on prioritizing tasks for collaborative mapping has been conducted in a natural disaster scenario (Hu, Janowicz, & Couclelis, 2016). The prioritization in this case relied on additional information on road networks. The concept applied information value theory to determine priorities of areas with regard to road connectivity for relief trips into disaster affected areas.

2. Analysis framework

The approach proposed in this paper is to leverage the capabilities of automatic image analysis to support the manual conflict damage assessment in remote sensing images. For this purpose, two aspects are considered. First, automatic algorithms can be used to *reduce* the areas of interest for a specific investigation. This is specifically important in large, rural regions where the areas of interest, i.e. the areas possibly affected by conflict, cannot be clearly defined a priori. This is also the case in our study area, Darfur, where small settlements are spread over wide areas and the locations of these settlements are sometimes very difficult to determine (American Association for the Advancement of Science, 2007).

Second, information derived from automatic methods can help *coordinating* the engagement of volunteers. This includes the prioritization of areas guiding the assignment of analysts and the sequence in which different areas are to be mapped. There is only little research about the

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[1] see http://www.standbytaskforce.org/(accessed 2017-07-17).

[2] see http://www.giscorps.org (accessed 2017-07-17).

[3] see http://www.tomnod.com/(accessed 2017-07-17).

[4] see http://tasks.hotosm.org/about (accessed 2017-07-17).