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Improving Human Rights Monitoring through Innovative Geospatial Technology Applications

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Geospatial technology provides a novel method of monitoring human rights violations in conflict zones. This technology is especially useful when reporters and aid workers do not have access to conflict zones because of restrictions from local governments or the danger of violence. Human rights activists have used images provided by satellites to document human rights abuses around the world, and some of these images have been used as evidence of human rights abuses in international humanitarian courts. However, there is great potential for advancement in the monitoring process. This paper aims to introduce the geospatial human rights monitoring process and to discuss how various technologies and algorithms can improve it.

Geospatial technology use has, for much of its recent history, been reserved for governments with access to satellites. In recent years, however, the technology has spread to various other actors (Edwards & Koettl, 2011). Non-governmental organizations (NGOs) like Amnesty International (AI) and the American Association for the Advancement of Science (AAAS) have accessed images from Darfur,

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Zimbabwe, Lebanon, Burma, Somalia, North Korea, and Sri Lanka by remote sensing with geospatial technology. Toney et al. (2010) note that the satellites capture high-resolution panchromatic and color images to “rapidly convey information about the natural world as well as human activities occurring on earth’s surface” accurately (p. 1015), which is of great help to human rights activists. Through remote sensing these organizations have been able to “document widespread destruction of buildings and communities…detect mass graves, document forced displacement, observe troop buildup, find secret detention facilities,” and more (Edwards & Koettl, 2011, p. 70). These efforts have revealed abuses that may otherwise have gone undetected or have been grossly underestimated. Such remote data collection is crucial for human rights, as conflict zones can be very dangerous to enter (Toney et al., 2010). Furthermore, access to the conflict zones could be blocked by local governments (US Fed News Service, 2008). These factors can impede the collection of on-the-ground evidence by human rights activists. Fortunately, NGOs are able to purchase imagery from private companies that operate sensors like Ikonos, GeoEye, and DigitalGlobe, which possesses the QuickBird and WorldView satellites (Toney et al., 2010). They may also request geospatial images through an application process from the U.S. Department of State (Systems and Integration Office, n.d.). These powerful technologies have certainly aided the human rights workers in their efforts, and have revolutionized the field of human rights monitoring.

In 2005, the AAAS began the Geospatial Technologies and Human Rights project with a grant from the John D. and Catherine T. MacArthur Foundation (US Fed News Service, 2008). Shortly after it received the funding, the AAAS teamed up with AI in 2006 to document the destruction of the Porta Farm settlement in Zimbabwe with the aid of geospatial technology. The NGOs provided images of the atrocious destruction to lawyers from Zimbabwe to support their litigation efforts. Satellite images have been used as evidence in courts even before this incident. U.S. government satellite images were submitted as evidence for the genocide prosecutions at an International Criminal Tribunal for individuals who were involved in the massacre of Bosnians in the former Yugoslavia, including Slobodan Milosevic (Keeley & Huebert, 2004). In order to document such atrocities around the world, analysts evaluate images of one location over time to detect change. They can use satellite images to identify the destruction of villages, movement of populations, digging of mass graves, and more. To provide more context to the satellite images, the analysts overlay the images with GIS layers and the locations of eyewitness reports that provide context and guide analysis, or use additional related data from other satellites that may have sensors that can detect fires (Marx & Goward, 2013). Although the images may not be able to show the specific cause of the fires, they can provide valuable insight when combined with on-the-ground witness reports (Vos et al., 2008).[2]

In addition to AAAS and AI, the Satellite Sentinel Project (SSP) has also championed the use of satellite imagery to document human rights abuses. SSP is a partnership between DigitalGlobe and the Enough Project (Kumar, 2013). It represents a joint effort between the non-profit sector and private sector for the betterment of mankind. During the crisis in Sudan, DigitalGlobe satellites collected imagery of over 750,000 square kilometers of Sudan (DigitalGlobe, 2011). During this crucial period, the SSP was able to "accurately monitor actions on the ground in Sudan" so that it could aid civilians on the ground (DigitalGlobe, 2011). The SSP had an extensive network of journalists and human rights monitors working with them, which allowed them to acquire a stream of imagery that corresponded to developments in the country. Consequently, the SSP could warn civilians accordingly (Kumar, 2013). Their efforts led to imagery acquisition of Sudan Armed Forces burning civilian homes in South Kordofan state. By combining geospatial technology with other forms of technology, this effort allowed for the effective warning of civilians and it revealed atrocious acts committed by the Sudan Armed Forces. This testifies to the power that the technology has in aiding human rights efforts.

[2] An interactive map of all human rights case studies conducted by AAAS can be found at: http://www.techforhumanrights.wordpress.com (see also: Luta, 2014).

As demonstrated by the geospatial human rights case studies conducted by organizations such as AAAS, human rights imagery analysts perform much of the analysis work manually. This process involves scanning and studying images with their own eyes to determine the existence and extent of human rights abuses. The process is laborious, time-consuming, and limited by the expertise and experience of the imagery analysts. However, there are a variety of technologies and algorithms utilized for geospatial analysis in other fields that can be adapted to greatly improve the work of the human rights imagery analysts. These technologies, which have been used to track deforestation, detect Egeria on bodies of water, map epidemiological phenomena, and more, can provide innovative ways of improving the efficiency and effectiveness of human rights monitoring. These technologies are advantageous in many respects, but they also have limitations. Nevertheless, human rights analysts can benefit greatly by using them. This paper aims to provide an introduction to these various technologies and to explain how they can be adapted to a human rights context so as to improve the geospatial human rights monitoring process.

2. Methods for Pre-Processing and Analysis of Geospatial Images

2.1 Pre-Processing and Correction of Geospatial Imagery

In some situations, specific conditions may pose obstacles to detecting change in satellite images over a period of time. Images may contain cloud cover, be unusually bright or dim, or be taken at an angle that obscures features of interest from sight. Not only can correcting images aid geospatial analysts involved in human rights investigations, but it can also make change-detection algorithms more effective. These algorithms are designed to detect modifications between different images of the same location over time, and they have been particularly useful in environmental studies such as monitoring deforestation (Morton et al., 2005). For example, given two or more images of a forest at different points in time, such algorithms can detect a change in tree cover and relay that information to analysts so as to draw their attention to specific areas of significant deforestation. If, for instance, one image has clouds and the other does not, or one image is brighter than the other, the algorithm would detect change in the images due to cloud cover or brightness. These changes are of no interest to the deforestation analysts, who are only concerned with changes in tree cover in the images. In order for this process to be performed effectively, images must first be corrected for conditions such as radiance and cloud cover. As Robert Rotberg (2010) notes, if human rights abuses are occurring around wooded areas, they could be accompanied by deforestation. Therefore, using deforestation-tracking algorithms can be used to identify human rights abuses. If these conditions are met, this could be a straightforward and invaluable method of detecting human rights abuses that requires no modification of existing algorithms.

Fortunately, methods exist to correct geospatial images. These image correction algorithms can correct radiometric errors (differences due to brightness), atmospheric errors (differences due to atmospheric conditions), and topographic conditions (differences due to topography) (Goslee, 2011). Such differences may be due to the time of day, time of year, suspended aerosol particles, and weather conditions. More specialized correction algorithms are also available. For example, researchers have developed an algorithm that corrects for differences in forest phenology over time (Isaacson et al., 2012). They used a metric known as "days left in season," or (DLiS) to "produce a synthesized phenological trajectory of the normalized difference infrared index," allowing them to gauge phenological trends (p. 529). Such an algorithm would allow change-detection algorithms to be more effective by minimizing the effect of changes that are not of interest, like seasonal foliage variation. Anjos et al. (2014) show that remote sensing platforms like World View-2 record data in eight multispectral bands. Since clouds and aerosol particles are only visible in certain bands, by aggregating information from all bands, algorithms can produce cloud and aerosol masking for remotely sensed data

(Anjos et al., 2014). As cloud cover can severely inhibit effective analysis of human rights conflict zones, such an algorithm may have great potential utility.

2.2 Algorithms for Geospatial Imagery Analysis

As stated previously, human rights geospatial analysts may need to manually view images to investigate human rights abuses. This work can be very labor intensive, and certain features in the images may be difficult to distinguish with the human eye. Mathematical and statistical algorithms have enormous potential in aiding human rights geospatial analysts in their efforts. Image correction, and subsequent change detection algorithms are relatively new technologies, but their impact can be very valuable. Furthermore, as the technology develops, they will become more and more useful. In the near future, these algorithms may be able to automatically detect destruction of villages and relay that information to analysts, which could save valuable time. In this section I will discuss algorithms that may be of use to human rights activists.

One algorithmic approach uses Landsat imagery with high-resolution sensors to create a system to detect destruction of villages in arid environments. It uses the Landsat historical archive to create a historic spectral baseline for villages in an area of study in Sudan. Once an image deviates significantly from the constructed baseline, the algorithm detects change that occurred (Marx & Loboda, 2013). This algorithm relies primarily on the near-infrared band, which can be used to indicate destruction of plant cell structure. Fortunately, the near-infrared band is relatively unaffected by atmospheric scattering, so atmospheric conditions do not greatly affect the analysis. The results of the algorithm were compared to a U.S. government database of destroyed villages in the area of study. Marx and Loboda (2013) show that their results were promising as their estimates were within 16% of the U.S. government database, demonstrating a functioning system to alert human rights practitioners to a potential destruction of villages. The development of this technology and the corresponding algorithms is bound to lead to increased effectiveness of the alert system.

Another group of human rights researchers studied the destruction of villages in Sudan with a different algorithmic approach that relied primarily on albedo (Prins, 2008), or solar energy that is reflected from the Earth's surface. The advantage of this method is that it has 98.5% accuracy in detecting burned villages from change in albedo and is relatively low cost. This approach compared albedo from two images with a one year interval, and found that a decreased reflection pattern was linked to a village having been burned down (Prins, 2008). While this may also reveal decreased reflection patterns due to other causes, it still facilitates the process of monitoring human rights abuses. In principle it may be possible to combine this algorithmic approach with the near-infrared approach so as to create an even more accurate and effective method of monitoring the destruction of villages.

As certain features, such as villages and homes, are important in imagery analysis, feature extraction methods are also critical components of processing approaches for geospatial images. Foschi et al. (2002) note that feature extraction by image mining concerns the identification of patterns and generation of knowledge from large collections of images, especially the extraction of unique features for a particular domain. In order for this method to be effective, it is necessary to decide upfront what specific information is required from the images. Features may include colors combined with particular shapes, which require the retrieval of color and texture (Foschi et al., 2002). The feature extraction algorithm must first be run with training images for the software to learn what the features look like and be trained on how to extract them. The algorithm works by separating the images into blocks of pixels to allow the detection of certain features. If the blocks are too small, large scale features cannot be detected, and if the blocks are too large, small scale features cannot be detected. Ordonez and Omiecinski (1998) show that in the process of feature extraction, every image is treated as a matrix of data and each of its pixels is an element of the matrix. Researchers have used this method to detect

Egeria on bodies of water (Foschi et al., 2002). As the types of features to be identified can be pre-programmed, human rights activists have great flexibility in deciding what features to look for based on the type of human rights abuse likely to occur. Features to be detected could include villages or displaced populations.

Feature extraction can also be a step of a more complex image mining algorithmic method, where it is followed by other steps such as object identification, auxiliary image creation, and object mining. The mining of the images and alphanumeric data associated with those images can provide valuable results. For example, collecting weather satellite imagery of cities and the associated alphanumeric weather data can, when processed through an image mining algorithm, determine weather patterns for the cities under investigation. Furthermore, image mining patient data such as the combination of X-rays and alphanumeric data on health status can identify epidemiological associations of interest (Ordonez & Omiecinski, 1998). Such technology has broad potential use in human rights monitoring, as it may be able to determine patterns of violence and human rights abuses for specific geographic areas around the globe.

Shyu et al. (2007) developed GeoIRIS, a content-based multimodal Geospatial Information Retrieval and Indexing System, includes “automatic feature extraction, visual content mining from large-scale image databases, and high-dimensional database indexing for fast retrieval” (p. 839). It is a powerful system that combines much of the technology and algorithmic methods already discussed. GeoIRIS can identify database satellite images that have similar objects and spatial relationships to a given image. It greatly boosts analysts’ productivity by mining multimodal datasets of imagery and flagging imagery that may require the analysts’ attention. Its content-based image retrieval can extract image features “ranging from pixels, regions, and objects to higher level descriptors of objects in the image,” and can retrieve images with similar visual patterns (Shyu et al., 2007, p. 839). Inputting images of displaced populations into the system may allow it to find other images of displaced populations in other locations around the world.

The general feature extraction algorithm of the system is able to discern features by discriminating between land-cover and land-use patterns, like residential, urban, and cropland. The algorithm works by splitting images into tiles and creating spectral histograms of the tiles that summarize the measured pixel intensity distribution. These histograms are created for panchromatic, grayscale RGB, and near-infrared data. The pixel intensity distribution histograms allow the system to discern specific features in the tiles. Anthropogenic feature extraction is another powerful component of the system that concerns man-made elements like buildings and roads (Shyu et al., 2007). It accomplishes this goal by using linear feature extraction and differential morphological profiles (DMPs). Linear feature extraction is effective in distinguishing roads and paths. Before it is carried out, a vegetation mask is constructed using the Normalized Difference Vegetation Index (NDVI). It is important to note that this index is the same index used by the change-detection algorithms that are used to detect deforestation. High NDVI values indicate presence of vegetation, so these areas are excluded during the linear feature extraction process. This method increases accuracy in identifying only man-made structures. DMPs help identify man-made structures with a specific morphology or shape (Shyu et al., 2007). The technology of the GeoIRIS system and its powerful satellite image query features can certainly be of use to human rights analysts, who will benefit from systems able to automatically search for displaced populations and destroyed homes.

GeoCDX is a powerful and sophisticated change detection system. It is a “fully automated system for change detection of high-resolution satellite imagery,” that is “sensor-agnostic, resolution-independent and designed to process the very large volumes of data collected by modern high resolution panchromatic and multispectral imaging satellites” (Klaric et al., 2013, p. 2067). By controlling for many factors and utilizing powerful and sophisticated computational methods, this system has great potential for human rights abuse monitoring. A few of its important capabilities include automated coregistration of imagery, high-level feature extraction, change detection processing, and image tile clustering methods. Klaric et al. (2013) demonstrate that GeoCDX can process imagery from a variety of sources, and can accommodate many image formats, bit depths, spectral bands, and preprocessing levels. It also has a built-in system to prevent false change detections. For example, it uses ray casting techniques to create a shadow mask so that shadows are not confused with significant changes between images. In this process, a 3-D model is generated with the sun as a light source using the sun/sensor geometry metadata collected. A ray is cast from this light source to each pixel that the camera can see. If a ray intersects the constructed digital elevation model before reaching the pixel, this pixel is identified as under the shadow mask (Klaric et al., 2013). GeoCDX can work around cloud cover in addition to shadow cover.

Another useful feature of the GeoCDX system is that it can interface with Google Earth, as change intensity maps from GeoCDX can be overlaid in Google Earth. The GeoCDX developers have processed 4,121 image pairs with GeoCDX and have successfully coregistered more than 91% of the pairs corresponding to a total area of 370,000 km^2. The areas with unsuccessful coregistration had small overlap, so GeoCDX did not have sufficient key points in those images for coregistration. Also, the failed pairs differed by more than 1.5 times in elevation angle, which greatly affects image geometry and hence, coregistration. However, 91% successful coregistration is extremely high, and this percentage testifies to the power of the system (Klaric et al., 2013). GeoCDX is one of the most powerful change-detection systems available, and it has enormous potential in aiding human rights geospatial analysts monitor human rights abuses around the world.

2.3 Software Tools

2.3.1 R. R is a free, open source statistical programming environment, which is useful for performing statistical analyses including analyzing images (r-project.org). Individual developers can develop packages in R that can be downloaded and used by anyone. One package that is of relevance to human rights reporting is the Landsat package developed by Sarah Goslee (2011). This package demonstrates the potential for developing algorithms with the R language. She has implemented several correction methods so far, including atmospheric, radiometric, and topographic correction algorithms. This package takes advantage of the Landsat database of satellite images for analysis. The package works with Landsat images converted to digital numbers (DN). Pixel intensity histograms are created from the DN values of an image to allow processing in the Landsat package. As R is a statistical software, the image must be converted first to data for statistical methods to be applied. Such methods have already been used for image correction, and have potential in other areas, such as statistical pattern recognition (Goslee, 2011). Computer scientists and statisticians interested in geospatial analysis can make great use of R in developing and implementing algorithms to correct and analyze imagery. As R is free and open-source, it can serve as a starting point for those who want to improve existing geospatial algorithms or even develop their own.

2.3.2 MATLAB. While R is a relatively new tool for geospatial imagery analysis, MATLAB has a history of digital image processing, including geospatial imagery. In order to understand how MATLAB processes images, one must understand that a digital image is essentially a three dimensional matrix of numbers. Tomasi (2000) explains that each pixel has levels of red, green, and blue with specific numbers associated with them, which adds a quantitative dimension to the pixel colors. The varying levels of red, green, and blue can give rise to one of over sixteen million colors for a given pixel (Morley, 2009). The quantitative dimension can allow for mathematical and statistical analysis of images. Mujumdar and

Nagesh (2013) show that the MATLAB image processing toolbox analyzes pixels to perform tasks such as image restoration, enhancement, and information extraction. Furthermore, a histogram function shows the distribution of pixel intensities in the image. In a low-contrast image, MATLAB can increase the intensity of the higher-intensity pixels and lower the intensity of the already lower-intensity pixels to improve contrast. Other operations include image arithmetic, in which images are added, subtracted, multiplied, or divided. For example, as a means of change detection analysis, one image can be subtracted from another to clearly see changes between the two images (Mujumdar & Nagesh, 2013). With this operation, each pixel in one image is subtracted from the corresponding pixel in another to give a new pixel in the resultant new image. The two images "must be of the same size and class," as the pixels need to correspond (Mujumdar & Nagesh, 2013, p. 115). If this condition is met, the operation can be particularly useful for human rights monitoring, where such a function could indicate internally displaced persons (IDP) movement or destroyed shelters.

MATLAB users have generated their own algorithms by programming within the software. For example, Keen et al. (2004) note that users have created cloud removal and temperature contour algorithms in MATLAB. Even more specific algorithms, like one that calculates available roof area for solar panels in a city, have also been developed with MATLAB (Bergamasco & Asinari, 2011). This algorithm, which researchers applied to over 60,000 buildings in Turin, Italy, accounts for available roof surface, shadows, roof features, and azimuthal angles of potential solar panels. Based on this information, the results show available roof surface for solar panels. Because MATLAB has sophisticated color detection algorithms, by analyzing digital images of green areas, vegetation patterns and deforestation detection algorithms can be implemented (Kuthadi, 2005). Given the variety of tools and methods for digital image analysis in MATLAB, it can be effectively applied to geospatial imagery analysis for human rights.

3. Geographic Data Visualization

3.1 Geographic Information Systems

Geographic Information Systems (GIS) compile and process geographic and spatial data. For example, Elebead et al. (2012) conducted a study on cancer control in Sudan in which they mapped the distribution of cancer events by building a database with GIS. The spatial analysis capability of GIS allowed the researchers to estimate rates of cancer from the data they put into the system. Mapping data also allows time trends to be more easily distinguished (Elebead et al., 2012). As geospatial data is inherently spatial in its nature, it can easily be incorporated into GIS. An agricultural study using GIS conducted by Dung and Sugumaran (2005) noted that routine determination without GIS would make many factors difficult to determine, like whether or not features are adjacent to farm properties, the distance between structures, and the fragmentation of the landscape. The study successfully incorporated remote sensing data into GIS so that the researchers could get a clearer view of the land and to easily process the spatial data. They demonstrated that combining GIS and remote sensing provides sound evidence-based information for decision-making with regard to the agricultural landscape (Dung & Sugumaran, 2005). Furthermore, by combining remote sensing with GIS, Obiefuna and Uduma-Olugu (2011) could identify change in Nigerian wetlands over time. Additionally, they could also quantify the actual percent change. Lastly, a study of precipitation in Brazil showed that spatial distribution data from GIS could be analyzed with geostatistical methods to describe and explain precipitation trends (Silva & Simoes, 2014). The power of GIS and its ability to incorporate remote sensing data makes it particularly useful for human rights research. As a great amount of data pertaining to human rights abuses is geographic in nature, GIS has extraordinary potential in providing a full picture of areas where human rights are abused around the world. Mapping abuses in an area can provide a much better sense of the gravity of the situation and lead to faster and more effective responses. For example, GIS can show exactly where the affected populations are located and what the best way to deliver aid to them is.

3.2 Geovisual Analytics

Geovisual Analytics is a relatively novel field that takes methods from visual analytics and integrates them with GIS (Tomaszewski et al., 2007). It supports problem solving, situational awareness, and decision making with interactive, visual environments that incorporate various data sources. The tools of Geovisual Analytics aid in identifying relevant geospatial data employing analytical methods that combine human abilities with visual interfaces to better support analytical reasoning. Tomaszewski et al. (2007) explain how Geovisual Analytics can be very effective and efficient with regards to crisis management. Crises give rise to large amounts of data from various sources, including news, video, photos, email, and social media feeds. These data usually have a geospatial component or geospatial reference, such as a place name. Geovisual Analytics applications can extract and map geographic place names from news stories to illustrate relations between places in Google Earth. Essentially, Geovisual Analytics provides essential information in an interactive visual format that allows analysts to efficiently and effectively understand a situation and make decisions (Tomaszewski et al., 2007). As crisis management methods can be directly applicable to human rights conflicts, much of the strategies and applications the paper outlines can be of great use in human rights monitoring.

4. Discussion

4.1 Limitations of Geospatial Technology

For all the advantages that geospatial technology provides for human rights monitoring, several limitations and obstacles exist. Edwards and Koettl (2011) note that satellite images can only document abuses with a clear physical effect observable from space, for instance. Burned villages can be documented quite effectively, but if villages are destroyed by other means, it may be difficult to discern that from satellite images. Furthermore, satellite imagery cannot "document torture; it cannot document widespread and systematic rape in places such as the Democratic Republic of the Congo; it cannot demonstrate genocidal intent or conspiracy; it cannot distinguish between legal and illegal housing demolitions," and it cannot completely replace traditional investigation methods (Edwards & Koettl, 2011, p. 70). This was made obvious in Secretary of State Colin Powell's address to the UN, in which he made a case for the invasion of Iraq using satellite imagery without sufficient evidence that corroborated what was interpreted from the satellite images (Edwards & Koettl, 2011). Cingranelli et al. (2014) created a human rights dataset that contains data on specific human rights. The rights are split into two categories: physical integrity rights and empowerment rights. Physical integrity rights include extrajudicial killing, torture, political imprisonment, and disappearance. Empowerment rights include freedom of speech, freedom of movement, freedom of religion, workers' rights, and political participation. The AAAS case studies demonstrate that geospatial technology is best at providing evidence of physical integrity rights violations, especially extrajudicial killings. Even if remote sensing is better for monitoring violations of specific human rights, it must be combined with witness and press reports in order to give the geospatial evidence context and to verify what analysts believe the images are showing (Vos et al., 2008). Corroboration can lead to higher certainty and facilitate the decision-making and responses of human rights activists, courts, and governments.

Furthermore, high-resolution satellite monitoring requires manual analysis by imagery analysts, who must be trained and paid (Marx & Goward, 2013). Additionally, the satellite images they analyze are costly, and monitoring an area requires many images of that area over a period of time. The longer the conflict ensues, the more the costs aggregate. Vos et al. (2008) show that archive data for an area of 100 cubic kilometers may be purchased for a few hundred to a few thousand U.S. Dollars. Besides cost, satellites may be booked and unavailable to take pictures when needed, or their orbital paths may not cross the desired area of observation (American Association for the Advancement of Science, 2006). Various other factors may inhibit effective monitoring. Cloud cover, aerosols, tree cover, insufficient image resolution, smog, and even the angle at which a remote sensor takes an image can all pose problems to monitoring an area (American Association for the Advancement of Science, 2009). Such obstacles make monitoring difficult, even if funds are available for analysis.

However, despite the limitations, geospatial technology has proved successful in detecting human rights abuses, even if it cannot do so for all types of human rights abuses. Algorithms exist to correct some of the problems caused by atmospheric conditions and to enhance the quality of the images. Although price is an issue, partnerships with the private sector, like the partnership between the Enough Project and DigitalGlobe, can help alleviate the burden of high costs. These partnerships may be more likely to form if human rights activists identify and campaign for a pressing, humanitarian need that requires prompt retrieval of geospatial imagery from companies. A precedent for such a partnership exists, so certain companies may be willing to offer a reduced price or free services temporarily to help stop human rights abuses and hold perpetrators accountable.

4.2 Privacy Concerns

Some concerns over satellite imagery are that its use may violate privacy in some instances. However, it is important to note that visual tracking in public spaces is not generally considered an invasion of privacy because activities occurring in a public space are open information that most can access (Cen, 2011). Tracking activities constitute “an invasion of individual privacy and even cause reputation ruin and dignity loss,” according to scholars such as Cen (2011, p. 337). In the United States, the Fourth Amendment of the U.S. Constitution establishes a minimum standard for privacy. It reads: “The right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures, shall not be violated, and no Warrants shall issue, but upon probable cause, supported by Oath or affirmation, and particularly describing the place to be searched, and the persons or things to be seized" (National Archives, n.d.). With regard to photos taken from the air, the U.S. Supreme Court has ruled that evidence collected from aircraft traveling in public airspaces does not violate the Fourth Amendment. This was tested in 1978, when the Supreme Court determined that aerial photos taken of the Dow Chemical Company by the Environmental Protection Agency did not constitute a Fourth Amendment violation (Villasenor, 2013). In the U.S., geospatial imagery does not seem to cause legal issues.

Certain nations have more comprehensive privacy laws than others. For example, Silbert (2012) writes that Germany took Bing Streetside offline in 2012. Complaints about the service included that it displayed private homes. Microsoft started a system to conceal houses upon request, but citizens did not see that as sufficient. Google faced similar opposition in Germany, but was allowed to continue its street view service as long as it pixilated faces, license plates, and house numbers (Information Management, 2010). While the privacy protection measures from Germany are some of the strongest in the world, they address the street view services specifically. No major actions have been taken against overhead satellite imaging.

Different laws concerning aerial and spatial imagery, however, exist around the world. The threat to privacy of geospatial images is debatable, but the use of geospatial imagery in a human rights context currently has a strong precedent, given all of the conflicts that have been documented with it and the success of these efforts by human rights activists. Geospatial imagery has aided human rights activists' efforts and has been used in humanitarian courts. The potential threat to privacy must be put in that context, as geospatial imagery also holds human rights aggressors accountable for their abuses and can act as a deterrent to future abuses.

4.3 The Legal Use of Geospatial Imagery in Tribunals

Although satellite images have served as evidence in international courts in the past, some questions remain as to their status as evidence and admissibility in courts. Núñez (2012) notes that, in theory, there is no consensus as to the admissibility of these images for international litigation, and in practice courts have shown inconsistency in the admissibility of these images. The lack of accepted rules concerning images has led to various interpretations of their use in tribunals. In some cases they are treated as direct evidence, while in others they have served as circumstantial and indirect evidence. While their use in courts is varied, rarely do they serve as the only source of evidence in a court decision. In many cases, satellite images have been used as "corroborative evidence confirming other testimony and evidence," accompanying other forms of evidence for purposes of validation (Núñez, 2012, p. 20). If what the photographs show agrees with what other evidence indicates, it further enhances the credibility of the claims.

As far as international humanitarian tribunals are concerned, one judge of the former Yugoslavia tribunal praised satellite photographs' assistance in prosecution by showing mass grave sites and confirming witness accounts of civilian detentions and killings (Núñez, 2012). While a protocol for their use in courts does not yet exist, their value to international humanitarian cases has been demonstrated. Therefore, for future cases, a protocol is warranted to better serve justice. Chaturvedi (2015) recommends that "to expedite international human rights litigation, it is imperative that a proper mechanism or standard be established so that satellite imagery can be regarded in court as substantive evidence," as such a mechanism could make full and legal use of the potential of these images. She adds that the permissible resolution level of the satellite images and the purpose of the images must be directly addressed. Knowing this information can help determine the admissibility of the image in court as well as appropriate measures of enhancement necessary for the image to be used as evidence

(Chaturvedi, 2015). By addressing the use of satellite images as evidence, courts can come to decisions more efficiently, effectively, and justly.

5. Conclusions

Geospatial technology has been used by NGOs such as AAAS and AI to document human rights abuses around the world. Their efforts have been critical in describing and understanding situations on the ground and holding human rights abusers accountable. Geospatial imagery collected by these organizations has even been used as evidence in international humanitarian courts. While some cite privacy concerns due to the use of satellite imagery, much of it is not focused on remote sensing for the benefit of human rights monitoring. Currently, human rights imagery analysts are relying on manual labor to analyze imagery, while computer algorithms could be of great help to their efforts. Image correction and change detection algorithms have already proven their effectiveness in human rights monitoring, and as the technology develops, so will its potential for aiding in effective human rights monitoring. For activists wanting to make a difference on this front themselves, R and MATLAB provide promise for image analysis algorithms. Furthermore, remote sensing data can be integrated into GIS or Geovisual Analytics to gain a better understanding of human rights abuses in conflict zones. With more knowledge of such situations, decision-making and monitoring can be made more efficient and effective. The advantages and limitations of the various technologies described in this paper are summarized in the Table A1 in Appendix A. Furthermore, Table A2 summarizes the general advantages and limitations of geospatial technology applied to human rights monitoring.

There are a variety of potential avenues for further research in this domain. One avenue could be to study how best to apply these various technologies specifically to human rights. Such studies could measure the impact of the technologies in several ways, including how much time is saved, how much more efficient the analysts can be, what the error rates of the technologies are, and how cost-efficient implementation of the technologies is. These studies would also be helpful in identifying best practices and understanding how the technologies must be developed so as to be more effective. Geospatial technologies have developed profoundly over the last few decades, and they will continue to develop tremendously. Further research could also investigate new and other types of geospatial technologies and their applications to human rights. Lastly, one key area of research that would be of great benefit to the human rights community is the legality of using geospatial technology in court. While satellite images have been used as evidence in humanitarian courts, there are no clear standards and rules on the admissibility of satellite images in court. Individuals such as Chaturvedi (2015) and Núñez (2012) have noted this, and future investigation should further illuminate the reasons behind this lack of standards and what must be done to create them. This is important because, without proper admissibility standards, the advantage of acquiring geospatial evidence of human rights abuses is limited.

Several developments in satellite imagery also show promise for the future. PlanetLabs, a Silicon Valley start-up, constructs box-sized satellites called “cubesats” (Taylor, 2014). It has 28 satellites in orbit, and plans to release 131 of them by the end of 2015. These satellites are relatively inexpensive, and with so many in orbit, human rights activists will be able to better monitor conflict zones. Furthermore, a recent U.S. government decision now allows corporations to take satellite images at 31cm resolution. Before the decision, only satellites with resolutions of up to 50cm were allowed to take photographs (BBC News, 2014). Lastly, it would be helpful for human rights activists to learn from a joint effort between DigitalGlobe and The Nature Conservancy to track threatening invasive plant species in Hawaii (Kinver, 2014). This project has created an online platform consisting of satellite imagery of Hawaiian forests. Web users can access the platform to identify invasive species. The platform has built-in quality control mechanisms, and it has seen activity from thousands of users marking the locations of invasive species. This represents a unique, combined geospatial effort involving the public, the private sector, and a charitable organization that serves to help the Hawaiian environment. Geospatial technology has certainly seen enormous advancements in recent years. With more satellites in orbit taking higher-resolution imagery at a fraction of the cost and powerful algorithms and software available to process the imagery, it is up to human rights activists to take responsibility and full advantage of the various technologies they have at their disposal. If they do, the effectiveness and efficiency of their efforts can be maximized, abuses can be stopped, and lives can be saved.

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Appendix A

Table A1. Summary of the Advantages and Limitations of Specific Geospatial Technologies Applicable to Human Rights Monitoring.

Method	Advantages	Limitations
Image Correction Algorithms	• Prepares images for more effective change detection • Can correct for radiometric, atmospheric, and topographic differences (Goslee, 2011) • Advanced algorithms can correct for seasonal foliage variation (Isaacson et al., 2012)	• Requires original satellite data from various bands (Anjos et al., 2014) • Represents the first step in preparing images for detection of human rights violations

		• Cannot detect human rights violations alone
Burn Detection Algorithms	• Can automatically detect burning of villages and structures (Marx & Loboda, 2013) • Greatly reduces time • Up to 98.5% accurate (Prins, 2008) • Near-infrared band is relatively unaffected by atmospheric scattering (Marx & Loboda, 2013)	• Works best in arid environments • Manual work is required to verify the results • Requires data from near-infrared bands of satellite sensors or albedo measurements • Cannot determine the cause of burning or the motivation for it
Feature Extraction Algorithms	• Can identify specific features of interest in images (villages, homes, displaced populations, etc.) • Great flexibility in what features to look for (Foschi et al., 2002) • Can detect patterns over time (Ordonez & Omiecinski, 1998)	• Must initially specify what features to look for (Foschi et al., 2002) • Must use training images for specific features to ensure accuracy • Certain features may require more extensive training of the system • Certain human rights abuses may not be associated with specific features found in images (i.e. freedom of speech)
GeoIRIS	• Automatically extracts features (Shyu et al., 2007) • Can retrieve satellite images similar to a given image with certain visual patterns • Can mine large-scale databases for visual content • Combines multiple algorithmic approaches into one system	• Retrieving images with similar visual patterns will not necessarily be other images that show human rights abuses • Requires time to look through retrieved images to see which ones are of interest for specific human rights violations • Currently works with 0.6 and 1.0 m resolution imagery (Shyu et al., 2007) • Could benefit from novel algorithms, greater precision, and increased efficiency
GeoCDX	• Combines automated coregistration of imagery, high-level feature extraction, change detection processing, and	• Elevation angle and satellite azimuth can cause image

	image tile clustering algorithms into one system (Klaric et al., 2013) • Does not depend on specific image resolution levels or types of satellite sensors • Can accommodate many image formats, bit depths, spectral bands, and preprocessing levels • Can interface with Google Earth • Improves analysis efficiency and reduces likeliness of committing errors	coregistration to fail (Klaric et al., 2013) • Urban environments require more detailed analysis • Users require training and experience to maximize the technology's potential • The system could benefit from time series of high resolution satellite imagery
R	• Free to use • Users can develop their own image analysis algorithms (Goslee, 2011) • R packages are free to download	• Images must be converted into data, as R is a statistical language • Use is limited by the training and experience of the users
MATLAB	• Tasks include image restoration, enhancement, and information extraction (Mujumdar & Nagesh, 2013) • Can detect change through image subtraction • Image correction algorithms already exist	• Images must be converted into data for mathematical and statistical analysis • Images must be of the same size and pixels must correspond, limiting detection analysis • Use is limited by the training and experience of the users
GIS	• Users can create customized maps with relevant data • Contains methods for geospatial data analysis (Elebead et al., 2012) • Mapping data allows for trends to be easily distinguished (Silva et al 2014) • Effective for visualizing features and spatial characteristics (Dung & Sugumaran, 2005)	• Data processing effectiveness is available only for spatial data • Very limited in terms of algorithms such as image correction, burn detection, feature extraction, and change detection • Cannot analyze images, but can incorporate data from image analysis results • Cannot identify human rights abuses, but can help understand patterns of human rights abuses
Geovisual Analytics	• Helps identify relevant geospatial data (Tomaszewski et al., 2007) • Incorporates various data sources • Advanced analytical techniques can help reveal relationships, create categories, mine data, and lead to knowledge discovery	• Data must have a spatial component • Effective at making sense of human rights data, but cannot identify specific abuses

		• Does not create new evidence, but can help understand and visualize existing evidence and data

Table A2. Summary of the Advantages and Limitations of Geospatial Technology Applicable to Human Rights Monitoring.

Advantages	Limitations
• Saves time • Increases efficiency • Automates manual work • Can process information that humans cannot sense (infrared data for burn detection) • Improves understanding by visualizing information • Can correct for unwanted phenomena (cloud cover, image brightness, and topography) • Allows for customized analysis by looking for specific features (detectable features associated with human rights abuses include burnt structures, deforestation, mass graves, mortar/artillery craters, buildup of military vehicles, etc.) • Effective at detecting patterns across space and over time	• Cost • Human rights abuses must be visible from space • Limited access to data and satellites • Accuracy limitations • Algorithms may be less effective in urban environments • Technologies cannot determine the causes of or motivations for human rights abuses • Manual work is required to verify the results of geospatial analysis • Results must be corroborated with other forms of evidence on-the-ground • Analyst training and experience • Image resolution • In some cases, images must be transformed into data at the pixel level

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