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Geotagged photos: a useful tool for criminological research?

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Abstract

If a photo is worth a thousand words, is a geotagged photo worth even more?
Recent advances in Global Positioning System (GPS) and digital camera technology have enabled photographers to add an additional layer of context to their images. By linking photographs to the location where they were taken, geotagged photographs can be seen as source of qualitative and quantitative information. For example, such photos not only illustrate what you saw (qualitative) but when and where you saw it (quantitative). Typically used to document private social events and holidays, geotagged photos are a potentially useful research tool for criminologists. Many studies of crime draw from data related to criminal events, the environments that host crime, and the timing and placement of crime. This paper argues geotagged photos are a novel way to record such data quickly and efficiently. Moreover, the methodology is suitable for a variety of criminological inquiries and settings. Drawing from existing research using geotagged photos and two real-world applications of the approach to collect crime data, the paper's objective is to encourage criminologists to consider the utility of this low-cost, readily available, and easy to use technology.

Keywords: Geotagged photos; Graffiti; Ranger-based monitoring; Environmental criminology; Systematic observations

Background

What are geotagged photographs?

Digital photographs with spatial information are commonly referred to as geotagged photos. Geotagged photos are created in a variety of ways categorized as manual or automatic (Welsh et al. 2012). Automatic geotagging is possible using digital cameras with a built-in or connected GPS. Smartphones are an emerging system with a built-in GPS receiver (Valli and Hannay 2010) however many camera companies (i.e. Casio, Nikon, Panasonic, Olympus) also sell devices with this feature. Connected GPS units are aftermarket additions linked to a digital camera that enable it to capture spatial information. Both built-in and connected systems automatically save latitude and longitude coordinates to the Exchangeable Image File (EXIF) data of each JPEG file every time a photograph is taken. EXIF data also includes information such as the time/date an image was captured as well as basic information about the camera model and settings.

Separate from automated systems, manual geotagging involves editing the EXIF data of images that contain no location information. For example, photos taken with an ordinary digital camera will not show where each photo was taken. Using an EXIF editor, such as ExifTool or Exif Pilot, it is possible to add spatial information drawn from a variety of sources. One option involves comparing the time stamp of a photograph, to the time stamp of a GPS logging device and manually adding the coordinates. For users with no GPS equipment at all, location data may also be assigned by choosing locations on a map and linking these to the photograph using EXIF editing software.

In short, geotagged photos are created using multiple techniques and pieces of equipment. For research purposes, automated geotagging is preferred over manual geotagging as it saves time, does not require EXIF editing software, and is less prone to data entry mistakes. In the paragraphs that follow, the utility of geotagged photos for research purposes is discussed as are methods for turning raw images into useful data for criminological inquiries.

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Previous research using geotagged photographs

To date, there is limited academic research, especially social science research, that employs geotagged photos as a data source. Because geotagging is a relatively new technology this is not surprising and highlights the potential for innovative research to be done. This section is an overview of previous work using the quantitative and qualitative information of geotagged photographs as a primary or secondary data source.

Geotagged photos as a secondary source of information

Many studies employing geotagged photographs use publically available images found on photo sharing sites such as Flickr and Panaramio. For readers unfamiliar with these sites, they are online collections of photographs. The sites enable users to upload photos and add tags to images such as 'Statue of Liberty' or 'Oktoberfest' making it easier to find pictures using keywords. While some photos do not contain spatial information, and thus are not geotagged photos, a large proportion do. These have been used for various types of research, none of which have focused on crime or criminal activity.

Studies using publically available images posted on photo sharing websites are good examples of how geotagged photos can be used as a secondary data source. Generally, researchers see these photos as a non-invasive way to study human movements and the characterization of places and events. Because users post photos that contain spatial and temporal data, as well as tags which add context to the image, a great deal can be learned by piecing this information together. That said, answering research questions using the secondary data requires extracting GPS coordinates, time stamps, and user defined tags from the millions of photographs available. Because most research groups have a unique method for this, and extraction methods are not a central component of the current paper, this discussion focuses on what has been done with subsets of the Panaramio and Flickr images.

Spatial and temporal analyses of human movements are one of the most common ways geotagged photos have been used as a secondary data source. In essence, many research groups have tried to model how individuals and groups traverse time and space using geotagged photos as a proxy measure of their movements. For example, Jankowski et al. (2010) used a subset of Flickr images from the Seattle area in Washington State, USA to explore the movement of photographers. Taking usernames as the unit of analysis, the authors were able to track individuals and determine that most photography outings do not last long and tend to be concentrated in small areas of the city. Another attempt to link online collections of geotagged photos to spatial and temporal patterns include Orsi and Geneletti's (2013) effort to identify popular locations and model visitor flow to/from these locations inside a UNESCO World Heritage Site in Italy.

The work of Kisilevich et al. (2010) used geotagged photos from Panaramio and Flickr to explore how the data might be able to describe travel activities of users and the attractiveness of places. Using a data posted by users from large regions, namely Western Europe and North/South America, they performed spatial and temporal analyses to show where photos were clustered (place attractiveness) and how these clusters changed over time; visualising these clusters using different methods was a major objective of their work. The temporal analyses showed how large events, such as Oktoberfest, create spatial clusters that are time dependent. Building on this work Kisilevich et al. (2013) used time series analyses of geotagged photos from Switzerland to identify four types of spatial temporal clusters they define as: stationary, reappearing, occasional and regular moving.

Beyond spatial and temporal patterns that can be identified from collections of geotagged photographs, Rattenbury et al. (2007) explored how clusters in time and space relate to user defined tags. In essence, they wanted to see if it was possible to automatically define places and events based on the usage of tags over time and space. For example, spatial clusters of place tags should be stable over time while event tags will tend to be highly concentrated in both time and space. The authors believed their work on event and place semantics might be useful for improving image searches and other photo management tasks.

These studies are all examples of innovative research that can be performed using geotagged photographs. While the authors did not take the photos themselves for specific research purposes, they were able to learn a great deal about human movements and mobility from a unique secondary data source. It should be noted that while the volume of publically available photos is large, these data represent a subset of the population being studied. In other words, while a large number of tourists may visit an event such as Oktoberfest, only a percentage will make their photographs publically available. This limits the generalizability of the findings and highlights how using geotagged photos as a primary data source may give more complete information for certain research questions.

Geotagged photos as a primary source of information

Welsh et al. (2012) make a strong argument for the use of geotagged photos as a primary data collection tool. As geographers, they noted the importance of collecting spatial and visual information simultaneously to study a variety of research topics including: coastal erosion, the distribution of national chains vs independent retailers, vegetation successions and even crime signatures. Their pilot study explored geotagged photos as a tool for student

fieldwork and reviewed a number of smartphone apps to determine their utility for research purposes. The paper is a good source for beginners interested in learning more about geotagged photos as a general research tool.

Few studies have collected geotagged photos as a primary data source for a specific research project. The work of de Jong and Butynski (2010) is one example whereby geotagged photos were used to create Photo-Maps of primates in Kenya and Tanzania. The maps are meant to document and monitor different species based on phenotypes (physical appearance). They suggest this is a unique way to study primates and reduce the need to collect wild specimens for taxonomical comparisons. Another example is Quinn et al.'s (2011) work to monitor crop disease in developing nations using camera phones. Using photos of healthy and unhealthy cassava plants in Uganda, they experimented with image recognition techniques that would help farmers document disease outbreaks. They propose an approach using geotagged photos would reduce the need for expert surveyors and automate the diagnosis and modelling of crop disease. The limited use of geotagged photos as a primary data collection tool leaves much to be learned about this technique's applicability for scientific research.

Geotagged photographs as a criminological research tool

Previous research using geotagged photos indicates numerous topics can be examined using this type of data. Because geotagged photos have yet to be used in crime research, the potential to use the methodology for criminological inquiries appears untapped. From a visual perspective, photographs are a good way to document criminal events and the settings where crime occurs. From a spatial perspective, geotagged photos streamline the process of recording the location of criminal activity and linking it to observations of crime. Moreover, these photos are a low-cost, paperless approach to data collection that may save time and resources. This is especially true as image recognition and photo management software become more widely available and user friendly. By reducing the effort needed to collect and analyse data, researchers should be able to increase the size of study areas and/or the frequency of observations using a more automated approach.

In criminology, data derived from visual observations are typically used to study social and physical disorder. Drawing from the 'broken windows' argument proposed by Wilson and Kelling (1982), it is postulated that visual cues such as graffiti, litter and public drinking attract predatory criminals who see these as signs of community apathy towards crime interventions. Disorder is commonly measured by surveying residents about the problem in their area and linking it to crime or fear of crime (Skogan 1990; Perkins and Taylor 1996; Steenbeek and Hipp 2011).

Seeing the value of directly observing disorder, as opposed to measuring perceived levels, Sampson and Raudenbush (1999) used systematic social observations to quantify disorder in Chicago neighbourhoods. Using video cameras and observers, street segments in the study area were surveyed from the inside of a vehicle as it drove slowly down the street. Observer notes and video recordings were later used to determine the presence or absence of physical and social disorder. More recently, photographs have also been used to measure physical disorder for both criminological (Braga and Bond 2008) and health studies (Cannuscio et al. 2009). These research projects show the value of using visual data to better operationalize and measure theoretical concepts such as social and physical disorder.

In the past, photographs and videos of disorder were not collected using equipment with GPS. Instead, researchers would select the locations of photographs/videos *a priori* (Sampson and Raudenbush, 1999; Braga and Bond 2008) or locate them on a map after the fact (Cannuscio et al. 2009). If these studies were to be replicated using geotagged photographs, it is likely the data collection, management and analysis could be streamlined using a digital approach. Moreover, observations could easily be collected as point data providing researchers with greater flexibility regarding data aggregation and spatial analyses.

To further elaborate how geotagged photos might be used for criminological research the sections that follow give an overview of two field applications of this technology. The first is an example of using geotagged photos to quantify physical disorder in an urban area. The second shows how the same technology could be used to collect law enforcement data in rural settings. By presenting a case study from both and urban and rural environment, the paper aims to show the utility of geotagged photos for the study of very different crime types. Because crime occurs in a variety of environments, methods to study the phenomenon should not be limited to specific settings. Moreover, because crime is not confined to Western urban environments, exploring applications for studying crime in non-Western rural settings is important for the development of criminology around the globe. The case studies presented below draw attention to the strengths and weaknesses of geotagged photos as a research instrument and help formulate avenues for future research.

Methods

Case study #1: graffiti in Amsterdam

Graffiti, considered vandalism by some and art by others, can be found on almost every type of public and private property in urban areas. This includes homes, schools, bathrooms, and public transportation. From a

criminological perspective, graffiti is interesting because it is viewed as a type of deviance, physical disorder (Sampson and Raudenbush 1999; Innes 2004), and can be associated with other problems such as gang or drug activity (Ley and Cybriwsky 1974; Weisel 2002). That said, it is also considered to be an art form, especially by those who write or paint graffiti (Halsey and Young 2002). Research on graffiti has typically focused on motivations for painting graffiti (Halsey and Young 2006), differences between types of graffiti (Alonso 1998: Spocter 2004), and the link between graffiti and feelings of public safety (Austin and Sanders 2007).

As part of a Spatial Criminology course, a pilot study was conducted to explore the utility of geotagged photographs as a research tool for collecting data on graffiti. The idea was simple, by photographing graffiti it would be possible to record the type of property it was found on, the style of graffiti, and the spatial distribution. Although photographs and street surveys have been used to collect the same type of data before (Ley and Cybriwsky 1974; Alonso 1998; Spocter 2004), geotagged photos have not. It was thought a digital approach such as the one reported here would streamline data collection and analysis. The digital approach was not compared to traditional written survey methods in this pilot study but that would be an interesting research topic for future studies.

Using smartphones, instances of graffiti were documented in two neighbourhoods of Amsterdam, The Netherlands. Streets in the study area were surveyed for graffiti and other items such as CCTV cameras and 'vice' facilities. Vice facilities included bars, prostitution windows, casinos and places selling marijuana or magic mushrooms. Data collection occurred in two phases with 75% of the study area covered in one day and the remaining 25% a week later. A total of 1,845 photographs were taken the majority of which were observations of graffiti (n = 1,271). Using Quantum GIS, the photos were mapped and manually coded to indicate what was seen in the image. It was possible to add variables that detailed the type and quantity of graffiti in each photo as well as which were photos of CCTV cameras or vice facilities. Maps of these data and a further discussion of their distribution across the study area can be found in the Results section below.

Case study #2: monitoring wildlife crime in protected areas

In protected areas around the world, preventing wildlife crime is a major concern for conservation agencies. If left unchecked, crimes such as poaching and illegal plant harvesting have the potential to inflict enormous damage on ecosystems and wildlife populations. To keep this from happening, most protected areas have a law enforcement division tasked with detecting and deterring offenders; the necessity and utility of which are well documented (Leader-Williams and Milner-Gulland 1993; Hilborn et al. 2006). Like traditional police operations, wildlife rangers patrol their jurisdiction looking for illegal activity and record information about the *who, what, when, where and how* of crime (Leader-Williams et al. 1990; Nyirenda and Chomba 2012). Collectively, these patrol data can help monitor trends in illegal activity when analysed properly (Gray and Kalpers 2005). Moreover, they have the potential to help conservation agencies design data-driven prevention strategies and evaluate their effectiveness. Thus official records of illegal activity collected by ranger patrols are an invaluable tool for conservation efforts and important to the scientific study of wildlife crime.

Using such data to monitor and explain wildlife crime problems requires knowing a bit more about how illegal activity in protected areas is detected. Most importantly, it is well known that patrol data are not derived from a series of systematic surveys and thus only give data about patrolled areas (Gavin et al. 2009). Additionally, because the 'silent victims' (Lemieux et al. 2014) of wildlife crime cannot *call the police*, law enforcement records of illegal activity are heavily dependent on proactive, not reactive crime detection methods. This introduces what Yoccoz et al. (2001) describe as (a) detection error and (b) spatial variation and survey error. In general, the inability of rangers to *patrol the entirety of a protected area equally* and *be in the right place at the right time during all criminal events* means measures of patrol effort must be used to contextualize ranger patrol data. This avoids misinterpreting these data when using them for research and monitoring purposes.

To collect patrol effort and wildlife crime data simultaneously, various methods have been used by conservation agencies around the world; currently no international standard has been adopted. For example, some rangers will record the location of wildlife crimes and ranger movements during their patrol using handheld GPS devices (Stokes 2010). Others make marks on a printed map after they return from patrol (Jachmann and Bell 1984; Jachmann 2008). Patrol effort is typically quantified using a standard six or eight hour patrol day multiplied by the number of rangers on patrol (Jachmann 2008; Mubalama-Kakira 2010), or using actuarial numbers such as man days (Gray and Kalpers 2005), hours of patrol (Holmern et al., 2007), or distance covered (km) (Gray et al. 2009; Wiafe and Amoah 2012). When combined with observations of illegal activity, this enables the calculation of catch per unit effort (CPUE) indices that relate illegal activity detection to patrol effort. A standardized rate, using patrol effort in the denominator, is then used to compare spatial and temporal trends in illegal activity (Jachmann 2008; Mubalama-Kakira 2010). In short, this is how ranger

patrol data is typically collected and used to describe wildlife crime problems in protected areas.

In 2011 field tests were conducted in Uganda to determine if digital cameras with built-in GPS units could be used to collect ranger patrol data. In short, rangers need to make observations of where they go and what they see on patrol. The author believed geotagged photos and GPS tracks recorded by digital cameras would be a novel way to record such data. The author joined rangers in two protected areas on multiple patrols to determine how well such a camera would work in a rural and rather rugged environment. The camera model used was a Casio Exilim H20-G; in 2011 this model was commercially available at a cost of approximately 200 USD including a memory card and soft case. This camera was chosen based on user ratings and the relatively low price. The findings of Case Study #2 are discussed in the two-part Results section below. The first part describes how well geotagged photos captured the distribution of graffiti in Amsterdam for Case Study #1. The second presents findings from Case Study #2 concerning the utility of geotagged photos for wildlife crime data collection.

Results and Discussion

Case study #1: graffiti in Amsterdam

Figure 1 shows the spatial distribution of CCTV cameras, bars, and graffiti photographed during data collection for Case Study #1. The maps indicate each has a unique distribution across the two neighbourhoods in Amsterdam. Bars (n = 141) and CCTV cameras (n = 165) are concentrated in the grey neighbourhood, Burgwallen-Oude Zijde, home to the city's infamous Red Light District (RLD). Note the 1,271 photos of graffiti shown on the map represent 5,288 individual pieces of graffiti; most photos contained multiple pieces near one another. Graffiti is more evenly distributed across the neighbourhoods with 56% or 2,984 pieces found in Burgwallen-Oude Zijde.

The heavy concentration of CCTV cameras in and around the RLD is not unexpected given the large number of day and night visitors and the greater availability of vice facilities such as bars. Despite high levels of formal surveillance in Burgwallen-Oude Zijde, home to 90% of all cameras observed, more than half the graffiti observed was in this area. This indicates CCTV may have a limited effect on preventing graffiti and warrants further

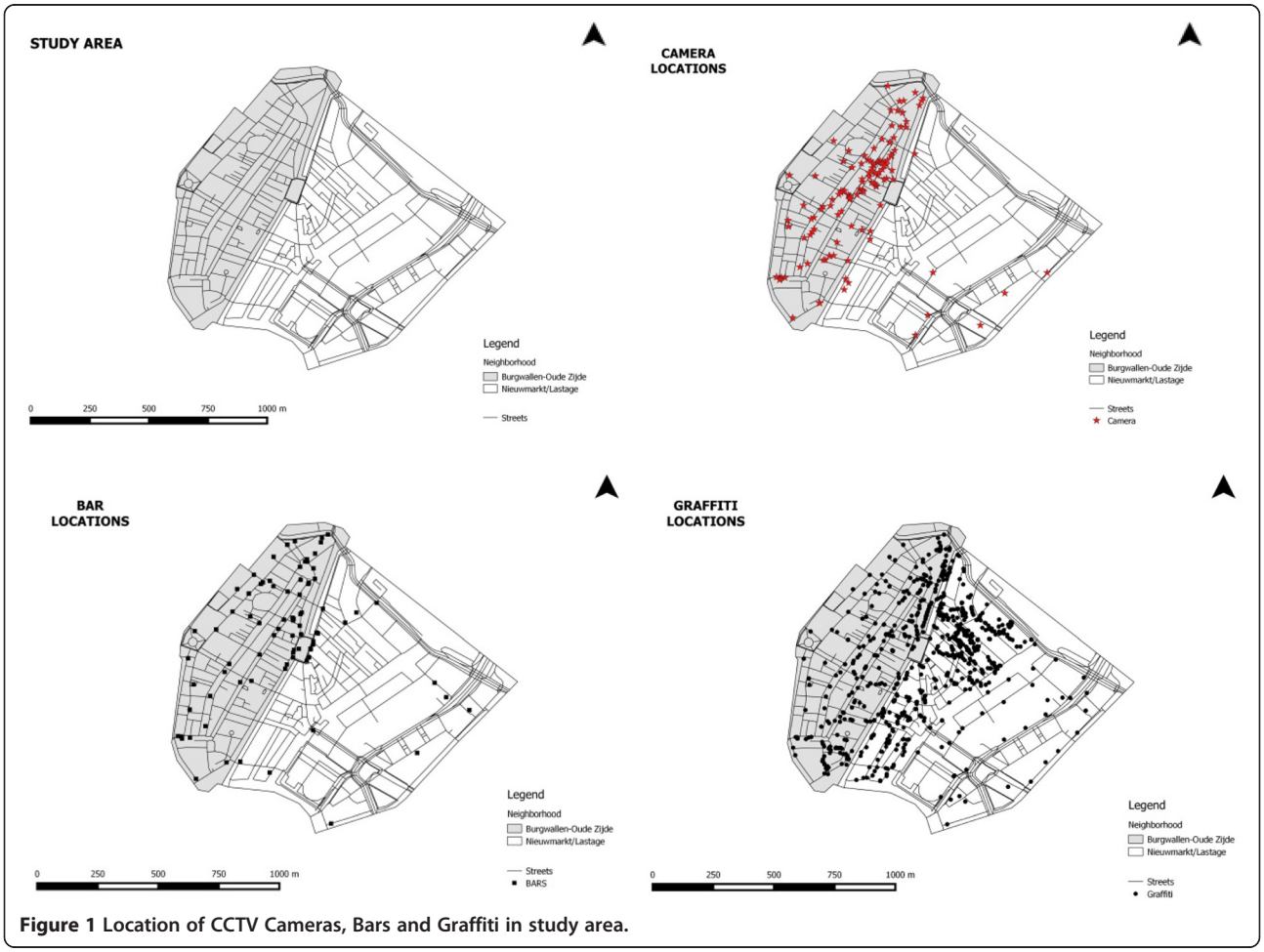

Figure 1 Location of CCTV Cameras, Bars and Graffiti in study area.

investigation. With a larger dataset, and more complex spatial statistics, it would be easier to determine how graffiti is related to vice and formal surveillance. That is not the purpose of this paper which instead is concerned with demonstrating geotagged photos would be an easy way to collect the data needed to address in-depth research questions.

Figure 2 shows the location of four exemplar photographs taken in the study area. The photos are meant to show the different types and quantities of graffiti found at individual locations. For example, Photos A and B contain examples of 'pieces' (Spocter 2004) while C and D are primarily comprised of 'tags' (Woodward 1999). Similar to previous studies (Spocter 2004), tags comprised 95% of all graffiti found in the study area. These photos also show the diversity of structures where graffiti was found including walls (A & B), private doorways (C), and around the window of a bar (D).

Strengths and weaknesses of the methodology

From this pilot study, a great deal was learned about the strengths and weaknesses of using geotagged photos as a research instrument. The major strength of this approach was that it was an efficient way to collect visual observations of graffiti using a quick and paperless system. The fact that these neighbourhoods were completely canvased in a matter of hours meant students spent minimal time on the streets; traditional street surveys using handwritten notes and paper maps would have required much more time. In areas where observer safety is a concern, geotagged photos enable data to be collected quickly and analysed later in a safe setting. That said, using valuable technology such as smartphones to collect data should also be considered when accounting for observer safety especially in areas where the risk of robbery is high. Finally, because photos were automatically geotagged students did not have to take notes about where they were, another time saving feature of the approach.

Limitations or weaknesses of the pilot study relate to the equipment used and the coding of photos. Regarding equipment, because students used their own personal smartphones the GPS information was collected using a variety of sensor models. This has the potential to

Figure 2 Examples of different graffiti styles observed using geotagged photos and their relative location in Amsterdam.

introduce variations in the precision of location information between different phones. This would be an important issue to consider if more detailed spatial analyses were conducted using the point data. Additionally, the process for manually coding the photos using Quantum GIS was a bit monotonous and would likely be made easier with photo management software. That said, the method is still believed to save time as even paper surveys would have to be digitized manually. Moreover, each photo was only viewed and coded by a single student. Future studies should consider having multiple students code the same photograph to examine the inter-rater reliability of the approach and increase the precision of the data.

Avenues for future research

Learning from this pilot, numerous avenues for future research can be thought of. By using geotagged photos as a research tool, criminologists could answer a number of questions related to the content and spatial distribution of graffiti such as:

1) Is it possible to create geographic profiles of individual graffiti artists?
2) What is the relationship between street lighting and graffiti?
3) Are anti-graffiti interventions effective?
4) How is graffiti distributed across different types of structures?
5) Is the content of graffiti (i.e. political messages, hate speech, etc.) related to the demographic and economic composition of the area/street where it is found?

Thinking about the methodology used to answer such questions, researchers should consider using the same camera model for all data collection, collect longitudinal datasets, and cover large study areas if possible. Moreover, integrating software that streamlines coding images would reduce the amount of time spent turning raw photos into useful research data. This would also enable each photo to be tagged by multiple individuals increasing the reliability of content analysis. In short, the pilot study presented here lends support to geotagged photos as a research tool that might help criminologists better understand physical disorder problems such as graffiti.

Case study #2: monitoring wildlife crime in protected areas

Figure 3 shows output from one of the test patrols in Queen Elizabeth Protected Area during Case Study #2. The patrol lasted for three days and covered a total of 46 km. While on patrol, the camera took a GPS reading every 10 seconds which was saved as a track of the patrol's movements. Looking at Figure 3, it is clear the tracking function on the camera worked well as there are only a few breaks in the track on Day 2. Because the patrol was conducted in the Maramagambo Forest, which is very dense with thick canopy cover, loss of the GPS signal at times was not surprising as even handheld GPS units carried by rangers encounter similar problems. The forest is a part of the larger Queen Elizabeth landscape which contains various types of vegetation including forested areas, savannahs, bush land and swamps.

Over the course of the three day patrol, various poaching signs were observed by rangers on the patrol team and photographed (see Figure 4); these included footprints, clothing left behind, and branches cut by poachers as they traversed the think forest. Three poacher campfires were also discovered and one suspect was apprehended at the end of the patrol for illegal firewood collection. These observations of illegal activity are shown in Figure 3. As with the graffiti study above, each photograph's location information was extracted and mapped using Quantum GIS. While the camera was carried on other patrols during the field tests, only one has been mapped here to give an example of output that can be created using the GPS camera. That said, the camera worked well on the other patrols and the GPS logging function had no problems when used in a savannah landscape with no canopy cover.

Strengths and weaknesses of the methodology

Numerous strengths and weaknesses of using geotagged photos to collect ranger patrol data were identified during the field tests in 2011. It is important to remember that patrol data is typically collected using handheld GPS units meaning that technology serves as a benchmark for comparison. Compared to handheld GPS units, the camera was able to make observations much more quickly and without the use of paper. The relative ease of using a digital camera vs a handheld GPS unit can also be seen as a strength of this approach.

Furthermore, the visual information provided by each photo was very detailed and if necessary would enable wildlife authorities, or researchers, to date items such as carcasses, poacher camps, etc. In other words, rather than an x-y coordinate with a written observation note, the photographs provided more context about what rangers actually encountered. Although not used in this pilot study, the video function on the camera could be used to document crime scenes and arrests when photos would not provide enough context. Additionally, automated GPS tracking ensured patrol coverage and effort (time spent in certain locations) was recorded in a standardized way. This is very useful for spatial analyses of ranger patrol data that must control for these variables (see Lemieux et al. 2014).

The most important limitation of using geotagged photos to monitor illegal activity in protected areas is the capacity needed to sustain such an approach. In

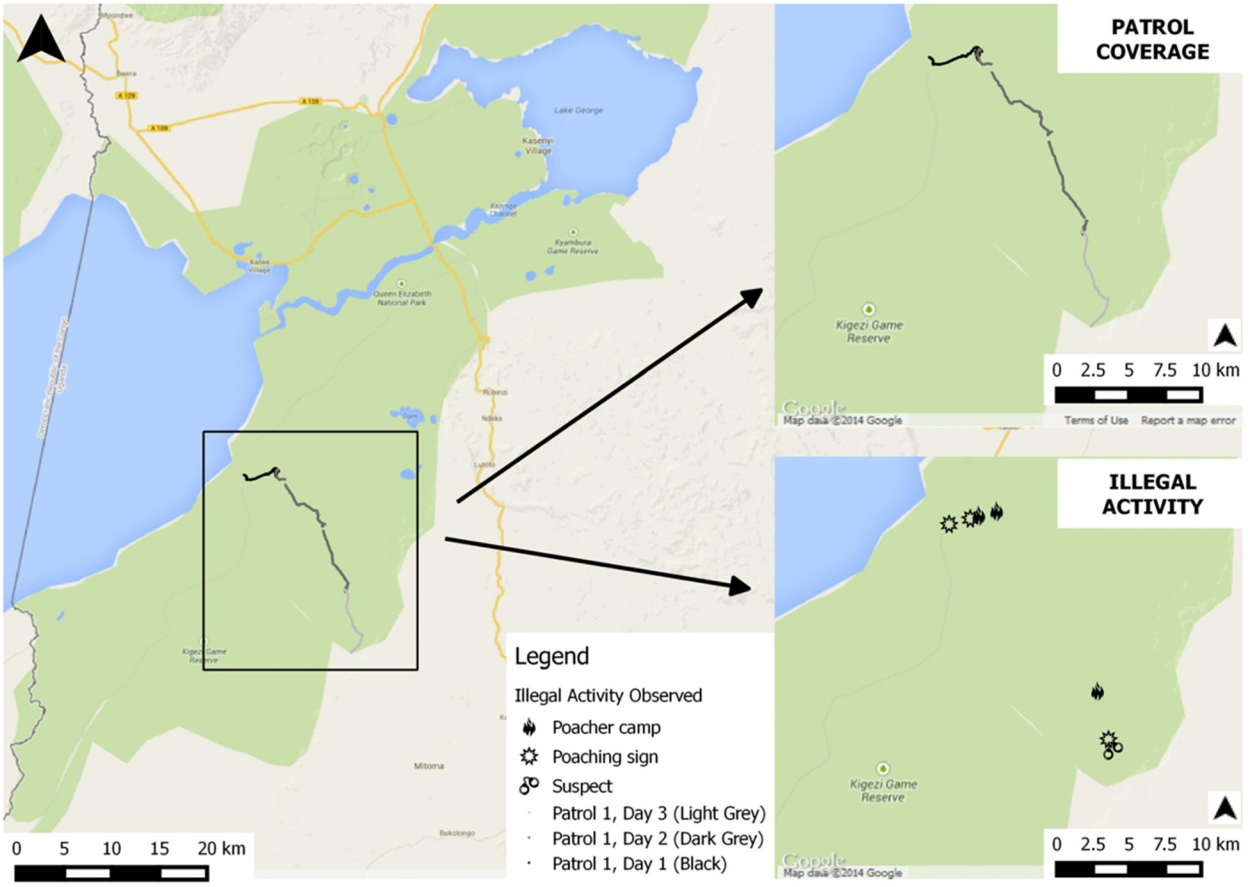

Figure 3 Example output of patrol data collected using Geotagged photos and GPS tracks.

essence, while the cameras would be very easy for rangers to use on patrol, turning the raw data into useful output for commanders and managers requires a unique set of skills; like those learned in a Spatial Criminology course. This is an obstacle to implementation that must be considered but could be addressed with adequate training. Finally, because the camera was unable to acquire the GPS signal in certain parts of the dense forest, the approach may not work well for protected areas with heavy canopy coverage. This is a limitation of the approach that would need to be considered to ensure illegal activity monitoring is not disrupted by features of the natural environment.

Avenues for future research

Building on learning experiences from the field tests presented here, a research project has been started in Uganda to further explore the use of geotagged photos as a tool for research and law enforcement operations. Because the data collection is on-going it is not possible to present the results of this project in the current paper. That said, examples of research questions that will be addressed using the new dataset include:

1) Can geotagged photos increase conviction rates by providing prosecutors with better courtroom evidence?
2) Do ranger patrols deter illegal activity inside protected areas?
3) Can patrol data help build simulation models of poacher activity?
4) How much ground can rangers cover effectively?
5) Do rangers, commanders and management find geotagged photos to be an improved way to collect patrol data or are handheld GPS units better?

In closing, the field application of geotagged photographs presented here is quite different than most criminological research projects that rely on visual data; such as those concerned with physical disorder. In this pilot study, geotagged photos are used as a way to collect spatially referenced law enforcement data with a minimal amount of effort and technical expertise. Such an approach is attractive when working with conservation agencies in developing nations where rangers exposure to technology may be limited making the introduction of complicated technology difficult and unsustainable.

Figure 4 Example photos of poaching activity detected on patrol.

Moreover, geotagged photos are not only useful for research on wildlife crime in protected areas, but also provide law enforcement divisions with stronger courtroom evidence for securing convictions. This means the technology has a great deal of potential for knowledge utilization if criminologists work closely with practitioners in the field; an important part of the research cycle.

Conclusion

The purpose of this paper was to present geotagged photographs as a potentially valuable research tool for studies of crime. Knowing that criminologists are often concerned with the locations that host crime, as well as contextual information about the crime itself, geotagged photos provide a unique way to capture information about both simultaneously. While academic research using geotagged photos is an emerging area amongst scientists specializing in automated data mining and visualization (Jankowski et al. 2010; Kisilevich et al. 2010; Orsi and Geneletti 2013; Rattenbury et al. 2007) most disciplines, including criminology, have yet to embrace the approach. The applicability of this technology to criminological research was evaluated in this paper using two pilot studies. In general, they showed that (1) the data needed to answer substantive research questions could be collected using geotagged photos and (2) collecting such data could be done with limited time and resources.

Should criminologists become interested in using geotagged photos as a measurement instrument various considerations must be kept in mind. Most importantly, the two pilot studies presented here have outlined their individual strengths and weaknesses that can be learned from. Major strengths of the approach identified by the pilot studies were (a) the ease of taking photos that contain spatial information, (b) the ability to use the method in urban and rural settings, (c) the large amount of situational context that can be observed with photos, and (d) the applicability of the approach to study different types of crime. Additionally, geotagged photographs provide criminologists with a good medium to study inter-rater reliability concerning the content of photos. By having multiple people blindly review and code photos, researchers can examine how well photos are capturing and measuring the variables of interest. Such an approach increases the reliability of measures and statistical analyses that use these variables to answer fundamental research questions. Finally, because geotagged photos are a standard way of making observations, the methodology would be useful for comparative studies. Collaborators could easily share photos that describe similar crime problems in different settings.

Regarding the limitations of this approach, researchers should remember that geotagged photos make it easy to collect raw data but adding context to the digital photo can require a significant amount of time depending on the number of photographs taken. Finding collaborators who might be able to automate this process using image recognition techniques or smartphone applications should be seen as a priority for streamlining data collection and

analysis. Also important would be recognizing the potential for abuse using geotagged photos whereby location and temporal data is digitally manipulated to alter results. This is especially true when using geotagged photos as a secondary data source as researchers cannot guarantee the authenticity of geotagged information posted by users on online photo sharing sites.

Finally, the second pilot study was able to show law enforcement officials and researchers alike could benefit from the use of geotagged photos. In rural settings such as a national park, spatial information is often hard to record as there are no streets or house numbers. Handheld GPS units are one way to record such information (Stokes 2010) but geotagged photos provide more detail that is useful for understanding crime problems and collecting evidence that can be used for prosecutions. While the example used in this paper took place in Uganda, a similar approach could be used in almost any rural setting to record crime data. For example, authorities charged with preventing the illegal smuggling of humans and drugs in remote areas might use geotagged photos to compile information about routes that are frequently used or where arrests are made. The photos could help officers on the ground better describe the problems they encounter to superior officers with visual evidence and minimal effort. In both urban and rural settings, geotagged photos would also be useful for documenting crime scenes and arrests as officers could map the location of these events making it clearer to judges where the crime occurred and prove suspects were apprehended at a specific location. In short, geotagged photos are not only useful for criminologists who study crime, but for operators in the field charged with detecting, deterring and prosecuting criminal offenses.

Competing interests

The author declares that he has no competing interest.

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References

Alonso, A (1998) Urban graffiti on the city landscape. Paper presented at Western Geography Graduate Conference, San Diego State University, Feb 14. Available online at: http://www.asu.edu/courses/aph294/total-readings/alonso%20–%20urbangraffiti.pdf [Accessed 28 August 2014].

Austin, DM, & Sanders, C. (2007). Graffiti and perceptions of safety: a pilot study using photographs and survey data'. *Journal of Criminal Justice and Popular Culture, 14*(4), 292–316.

Braga, AA, & Bond, BJ. (2008). Policing crime and disorder hotspots: a randomized controlled trial'. *Criminology, 46*(3), 577–607.

Cannuscio, CC, Weiss, EE, Fruchtman, H, Schroeder, J, Weiner, J, & Asch, DA. (2009). Visual epidemiology: photographs as tools for probing street-level etiologies'. *Social Science and Medicine, 69*, 553–564.

de Jong, YA, & Butynski, TM. (2010). Photographic maps of the primates of Kenya and Tanzania: a tool for identification and conservation. *Primate Conservation, 25*, 27–32.

Gavin, MC, Solomon, JN, & Blank, SG. (2009). Measuring and monitoring illegal use of natural resources. *Conservation Biology, 24*(1), 89–100.

Gray, M, & Kalpers, J. (2005). Ranger based monitoring in the virunga-bwindi region of East-Central Africa: a simple data collection tool for park management. *Biodiversity and Conservation, 14*(11), 2723–2741.

Gray, M, McNeilage, A, Fawcett, K, Robins, MM, Ssebide, B, Mbula, D, & Uwingeli, P. (2009). Censusing the mountain gorillas in the virunga volcanoes: complete sweep method versus monitoring. *African Journal of Ecology, 48*, 588–599.

Halsey, M, & Young, A. (2002). The meanings of graffiti and municipal administration'. *Australian and New Zealand Journal of Criminology, 35*(2), 165–186.

Halsey, M, & Young, A. (2006). 'Our desires are ungovernable': writing graffiti in urban space'. *Theoretical Criminology, 10*(3), 275–306.

Hilborn, R, Arcese, P, Borner, M, Hando, J, Hopcraft, G, Loibooki, M, Mduma, S, & Sinclair, ARE. (2006). Effective enforcement in a conservation area. *Science, 314*, 1266.

Holmern, T, Muya, J, & Røscraft, E. (2007). Local law enforcement and illegal bushmeat hunting outside the Serengeti National Park, Tanzania. *Environmental Conservation, 34*(1), 55–63.

Innes, M. (2004). Signal crimes and signal disorders: notes on deviance as communicative action'. *The British Journal of Sociology, 55*(3), 335–355.

Jachmann, H. (2008). Illegal wildlife use and protected area management in Ghana. *Biological Conservation, 141*(7), 1906–1918.

Jachmann, H, & Bell, RHV. (1984). Law enforcement in Malawi conservation: a monitoring system. *African Elephant & Rhino Group Newsletter, 3*, 7–10.

Jankowski, P, Andrienko, N, Andrienko, G, & Kisilevich, S. (2010). Discovering landmark patterns from photo postings'. *Transactions in GIS, 14*(6), 833–852.

Mubalama-Kakira, L. (2010). *Monitoring Law Enforcement Effort and Illegal Activity in Selected Protected Areas: Implications for Management and Conservation, Democratic Republic of Congo*. Ghent, Belgium: Ghent University. Faculty of Sciences.

Kisilevich, S, Krstajic, M, Keim, D, Andrienko, N, & Andrienko, G. (2010). Event-Based Analysis of people's Activities and Behavior Using Flickr and Panaramio Geotagged Photo collections'. *Information Visualisation (IV), 2010 14th International Conference, pp.289,296, 26-29 July 2010*. London, UK.

Kisilevich, S, Keim, D, Andrienko, N, & Andrienko, G. (2013). *Towards Acquisition of Semantics of Places and Events by Multi-Perspective Analysis of Geotagged Photo Collections* (pp. 211–233). Berlin Heidelberg: Springer.

Leader-Williams, N, & Milner-Gulland, EJ. (1993). Policies for the enforcement of wildlife laws: the balance between detection and penalties in Luangwa Valley Zambia. *Conservation Biology, 7*, 611–617.

Leader-Williams, N, Albon, SD, & Berry, PSM. (1990). Illegal exploitation of black rhinoceros and elephant populations: patterns of decline, law enforcement and patrol effort in Luangwa Valley Zambia. *Journal of Applied Ecology, 27*, 1055–1087.

Lemieux, AM, Bernasco, W, Rwetsiba, A, Guma, N, Dirciru, M, & Kirya, HK. (2014). Tracking Poachers in Uganda: Spatial Models of Patrol Intensity and Patrol Efficiency'. In AM Lemieux (Ed.), *Situational Prevention of Poaching*. Oxon, UK: Routledge.

Ley, D, & Cybriwsky, R. (1974). Urban graffiti as territorial markers'. *Annals of the Association of American Geographers, 64*(4), 491–505.

Nyirenda, VR, & Chomba, C. (2012). Field foot patrol effectiveness in Kafue National Park, Zambia. *Journal of Ecology and the National Environment, 4*(6), 163–172.

Orsi, F, & Geneletti, D. (2013). Using geotagged photographs and GIS analysis to estimate visitor flows in natural areas. *Journal of Nature Conservation, 21*, 359–368.

Perkins, D, & Taylor, RB. (1996). Ecological assessments of community disorder: their relationship to fear of crime and theoretical implications'. *American Journal of Community Psychology, 24*, 63–107.

Quinn, JA, Leyton-Brown, K, & Mwebaze, E. (2011). Modelling and Monitoring Crop Disease in Developing Countries. *AAAI Conference on Artificial Intelligence, North America, Aug. 2011*. http://www.aaai.org/ocs/index.php/AAAI/AAAI11/paper/view/3777. Accessed 01 Feb 2015

Rattenbury, T, Good, N, & Naaman, M. (2007). *Towards Automatic Extraction of Event and Place Semantics from Flickr tags'*. Amsterdam, The Netherlands: Proceedings of the 30th annual international ACM SIGIR conference on research and development in information retrieval, July 23–27.

Sampson, RJ, & Raudenbush, SW. (1999). Systematic social observation of public spaces: a new look at disorder in urban neighborhoods'. *American Journal of Sociology, 105*(3), 603–651.
Skogan, W. (1990). *Disorder and Decline: Crime and the Spiral of Decay in American Cities*. Berkeley: University of California Press.
Spocter, MA. (2004). This is my space: graffiti in Claremont, Cape Town'. *Urban Forum, 15*(3), 292–304.
Steenbeek, W, & Hipp, JR. (2011). A longitudinal test of social disorganization theory: feedback effects among cohesion, social control and disorder'. *Criminology, 49*(3), 833–871.
Stokes, EJ. (2010). Improving effectiveness of protection efforts in tiger source sites: developing a framework for law enforcement using MIST. *Integrative Zoology, 5*, 363–377.
Valli, C, & Hannay, P. (2010). *Geotagging where cyberspace comes to your place'. Proceedings of the International Conference on Security & Management* (pp. 627–632). Las Vegas: CSREA Press.
Weisel, DL. (2002). *Graffiti*. NW Washington, D.C: US Department of Justice, Office of Community Oriented Policing Services.
Welsh, KE, France, D, Whalley, WB, & Park, JR. (2012). Geotagging photographs in student fieldwork. *Journal of Geography in Higher Education, 36*(3), 469–480.
Wiafe, ED, & Amoah, M. (2012). The use of field patrol in monitoring of forest primates and illegal hunting activities in Kakum Conservation Area, Ghana. *African Primates, 7*(2), 238–246.
Wilson, JQ, & Kelling, G. (1982). The police and neighborhood safety: broken windows'. *Atlantic, 127*, 29–38.
Woodward, JD (1999). How to Read Graffiti. Available online at: http://www.kasino.com.au/masters/index.html [Accessed 11 December 2014].
Yoccoz, NG, Nichols, JD, & Boulinier, T. (2001). Monitoring of biological diversity in space and time. *TRENDS in Ecology and Evolution, 16*(8), 446–453.

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