Citizens as Indispensable Sensors During Disasters

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1 Introduction

The release of the seminal work "People and Pixels: Linking Remote Sensing and Social Science" in 1998 by the National Research Council marked an important milestone in the study of interactions and changes between the Earth and people [7]. The book was based on over 20 years of work with satellite data, primarily Landsat, and multiple observations that characterized human activities and their interaction with the environment. Since the publication, technological advances and population dynamics provided new challenges and opportunities.

Over the 20 years since then, our ability to observe the Earth and our environment has undergone tremendous advances by using multiple high resolution remote sensing instruments and dense networks of ground sensors to improve our collection of data. These observations are often used to initialize or validate numerical simulations, to reconstruct past events, and predict future outcomes at high temporal and spatial resolutions [9].

These advances in our ability to observe and simulate the environment are reaching a new peak with the increasing availability of high speed networks that allow for the sharing of data streams in real time, often wirelessly, and the availability of ubiquitous computing through mobile devices and cloud computing [22]. The combination of simultaneous access to high speed networks and computing capabilities give people virtually unlimited processing and storage regardless of their location.

Regular citizens have transformed from being receivers of knowledge, to becoming members of a bidirectional network where data are constantly generated and acted upon. Advances in technical capabilities to collect, store, and share environmental data led to the spread of "citizens as sensors" [12] who contribute to solutions for our planet. An important area of application is the use of citizen science data for response to environmental changes and as a source of human relevant information during disasters [18, 3, 1].

Disasters pose a significant threat to the development and sustainment of our society. Rapid population growth, the emergence of megacities, and high risk facilities such as dams and nuclear power plants have increased the risk posed by natural hazards at unprecedented levels [27]. A single catastrophic event in a populated area can claim thousands of lives, cause billions of dollars of damage, trigger a global economic crisis, destroy landmarks, render a large territory uninhabitable, and destabilize the political balance in a region [16]. Remote sensing is now the de facto standard for observing changes during disasters, but atmospheric conditions, revisit time, and constraints on tasking can limit the relevant data that can be collected from satellites.

Historically during disasters, citizens have been passive receivers of information from official government bodies. People were not viewed as a potential asset, but rather considered to be a liability [13]. Citizens only had a limited role as providers of opportunistic actionable data through communication of emergencies to responding agencies. There is a growing realization of the role of the local neighborhood level being the first response during severe events. William Craig Fugate the 2009 to 2017 administrator of the Federal Emergency Management Agency (FEMA) said that "Those that were saved were often by the person next to them, and the bigger the disaster, the more we have to realize that the public is a resource and not a liability, and reengage the public as part of the solution." [11]

Today, citizens are participating during crises to provide data and they even make it publicly accessible in real time. These data provide a unique perspective by being collected in areas of human activity and are often able to fill gaps in situational awareness [14]. Concerns over data quality and reliability are actively being addressed by researchers as these new sources of data are being evaluated case by case [24, 10, 17]. This paper advocates for "citizens as indispensable sensors" during disasters. Citizen science data are not viewed as opportunistic and relegated to the role of merely complementing official observations, but they are proposed as an essential source for situational awareness during crises.

2 A Completely New World

The rapid population change, remote sensing technological advances, and the development of the internet have drastically changed the world.

2.1 The "People" Became a Crowd

These transformational changes occurred at a time of drastic population increase worldwide, which gave billions of people easy access to data about the Earth, and at the same time, it allowed for the precise characterization of evolving demographics. The data are sometimes free and easily accessible, which allows for the study of human activities that goes beyond the statistics that can be captured in a census survey. Examples of activities that can easily be captured using digital technologies include patterns of commute, social relationships, and political opinions [25].

Instead of using decadal counts based on census data, patterns of human activity and information about the environment can be observed using Volunteered Geographic Information (VGI). Citizen science projects for environmental monitoring make use of "citizens as sensors" to intentionally collect data through crowdsourced observations [14]. The data are stored and quickly disseminated using social networks or dedicated services, and become available to study specific phenomena. Even data collected with no scientific intent can become crucial for scientific analysis because they provide unique observations not available in other forms [22, 8].

There is an ever increasing amount of VGI available, and they provide unprecedented access to observations of a physical state and traces of human activity. In addition, VGI often carry a subjective quality in the way they are sampled [25]. For example, a specific spot can be photographed numerous times, which can be used to determine its popularity, and a change over time might be observed. Therefore, the subjective interest of citizens is captured by their activities and sharing patterns. Furthermore, citizens often do not act as single entities, but as part of a crowd, and therefore, multiple observations are often available from multiple people. This led to the development of smart and connected communities, where data are shared and organized in real time for decision making [4].

During disasters, VGI are particularly important because they can provide actionable data for response and recovery [28]. Images of flooded areas collected in front of homes can be used in combination with traditional remote sensing imagery to determine very accurate inundation boundaries [20, 21, 5, 23]. Sometimes, citizens are the only provider of data during stages of disasters, because other official sensors are not available, either because they have not been deployed, they are damaged, or because of physical limitations that prevent data collection. The availability of VGI provides a necessary input as emergency models are transitioning from providing solutions to hypothetical pre-computed scenarios to proving real time solutions that reflect evolving events.

2.2 The "Pixels" Became Finer and Faster

Satellite remote sensing technology evolved rapidly since its development in the 60s and 70s. By the late 80s enough data were collected to study the changing planet, which led to review of contributions in "People and Pixels" [7]. Nowadays, observations are available from a network of Earth observing satellites that collect data at a much finer spatial, temporal, and spectral resolution. Crucial providers for this diversity of data has been the deployment of sensors by multiple space agencies and by the commercial sector. These developments have led to new understandings of the planet, and allow for the study of changes at a much finer resolution.

Furthermore, whereas satellite remote sensing was at first relegated to scientific and military applications, it has found its way into people's daily activities. Remote sensing data are used by the general public to make decisions when buying homes, exploring new sites, and it is the de facto news standard to show changes using imagery taken before and after major disaster events.

A new major development is the availability of inexpensive UAS that can be quickly deployed by citizens to collect high resolution imagery and videos, paired with the ability to share them with free and reliable mechanisms [26, 2]. These data have been shown to provide unique views to assess damage, and in turn, can prove to be crucial in the validation and calibration of models.

However, this widespread use of remote sensing data in science and daily life could not have advanced this fast if it was not for the accessibility of data through simple interfaces, and the fact that most data, especially for science, can be obtained free of charge. Simple browsers from major data providers, both government and commercial, provide quick views of data, so that they can be inspected for a quick assessment before being downloaded. The volume of the data are, in fact, very large, so providing them to the end user quickly and reliably required the development of sophisticated and expensive cyberinfrastructure.

Therefore, the pixels have become finer because of the higher spatial resolution at which they are provided. They are also faster not only because they are collected at a higher temporal resolution, but also as they can be accessed more quickly.

2.3 The Earth Became More Connected

In a period of less than a generation, the internet has transformed key aspects of daily life, from redefining human interactions, to accessing information, forming opinions, and making decisions. While at first the internet was primarily intended for person to person data sharing, it quickly became one to many with the emergence of the World Wide Web and social media networks. The emergence of internet devices that share data, and are at times able to talk to other devices with no human interaction, led to paradigms such as the internet of things (IoT) and infrastructure as a service (IaaS) [25]. These changes led to the collection of unprecedented massive amounts of data about people and their daily interaction with the world. The generation of data is faster than our ability to analyze them, and this is quickly leading towards a data-rich but knowledge-poor environment [19].

The concept of Digital Earth is expanded to include the infrastructure, data, and tools that are used for the acquisition, storage, visualization, and sharing of spatio-temporal patterns about the Earth, the environment and the people. Building a digital earth is paramount for the study of the interaction between people and the Earth, and to elevate from data to knowledge. The fusion of imagery and social data can bring street-level insights about populations during disasters [15]. Understanding and acting upon these interactions is critical during emergencies to protect people, properties, and the environment.

CyberScience, or more specifically geoinformatics algorithms, are needed to address these scientific and computational challenges and to provide innovative and effective solutions to analyze these large, often multi-modal, spatio-temporal datasets [6]. Traditional data mining techniques are ineffective as they do not incorporate the idiosyncrasies of the spatial domain, which include, but are not limited to, spatial autocorrelation, spatial context, and spatial constraints.

3 Conclusions

During the last 20 years since the initial publication of "People and Pixels" the world underwent profound environmental and population changes. Our ability to collect higher resolution data, including VGI, was paired with advances in networking and storage solutions. Now, a new vibrant landscape exists that pairs the digital Earth with the physical Earth, which provides new opportunities and challenges.

Disasters play a fundamental role in society, and their study is necessary for improving resilience and minimizing losses. The active participation of "citizens as indispensable sensors" shifts their role during disasters from passive to active. This new solution assumes that actionable data can be collected during disasters, and that these data are both indispensable and more economical compared to the deployment of a dense official sensor network.

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