Overview of Data-Driven Hazard Detection Research at WSU's Disaster Resilience Analytics Center for Enhancing Community Resilience

Atri Dutta[1,*]

[1] Wichita State University, Wichita KS USA

Abstract

Early detection of hazards as well as the identification of geographical regions affected by a disaster play a substantial role in timely intervention and planning of disaster relief operations. We provide an overview of the current research efforts at Disaster Resilience Analytics Center for technologies that can facilitate early detection of hazard through collection and analysis of data by remote sensors, as well as identification of hazardous situations through analysis of social media data. The availability of these technologies can help reduce the risk of disasters, thereby improving the resilience of communities.

Keywords

Hazard detection, Artificial Intelligence, Sensor networks

1. Introduction

Wichita State University (WSU) is a public university located in the city of Wichita, the largest city in the state of Kansas, United States of America. In 2020, WSU initiated efforts to fund four convergent science teams for a period of three years. Disaster Resilience Analytics Center (DRAC) is one of these teams and is engaged in research and education in the field of data-driven disaster analytics. Currently, the DRAC team consists of fifteen faculty members from five different colleges (College of Engineering, Liberal Arts and Sciences, College of Applied Studies, School of Business and University Libraries).

1.1. Disasters

As per the United Nation's Office of Disaster Risk Reduction, a disaster is a set of hazardous events causing a serious disruption of regular functioning of a community, and having a significant impact on community residents, material property, economy, and environment [1]. While this broader definition can apply to pandemic events, large-scale industrial accidents, as well as man-made events, for the purpose of this abstract, we restrict ourselves to events due to extreme weather, such as hurricanes, floods, drought, winter storms, and wildfire. Since

International Workshop on Data-driven Resilience Research 2022, July 6, 2022, Leipzig, Germany
*Corresponding author.
atri.dutta@wichita.edu (A. Dutta)
https://www.wichita.edu/profiles/academics/engineering/aerospace/astronautics/Dutta-Atri.php (A. Dutta)
0000-0003-2191-0305 (A. Dutta)

Table 1
Impact of weather disasters (consumer price index adjusted data from NOAA [2]).

Decade	Number of Disasters	Impact (USD Billion)
1980 – 1989	29	178.1
1990 – 1999	53	273.6
2000 – 2009	62	518.1
2010 – 2019	119	810.3

1980, the United States (U.S.) has experienced at least 323 weather and climate disasters with damage/cost exceeding 1B US Dollars; National Centers for Environmental Information (NCEI) estimates the cumulative cost of such extreme weather events since 1980 as over 2.1T US Dollars [2]. Climate change has resulted in increased frequency as well as enhanced severity of such events. Review of data from National Oceanic and Atmospheric Administration (NOAA) during this period reveals that weather and climate disasters have not only become more frequent in the recent decades, but also more devastating as well (see Table 1); while this data covers only financial costs, note that there are significant human costs, deaths and trauma suffered by whole communities, which are not quantifiable in monetary terms. Furthermore, while it is easily perceived that the impact of weather events is significant and prominent in each geographical region, such as the coastal areas for the hurricanes, the damaging effect on critical infrastructures, such as power grids and oil rigs, impacts people's lives far beyond the region directly threatened by the disaster.

1.2. Community Resilience

As noted by Patel et al [3], there is a lack of consensus in the scientific literature, policies, and practice on a precise definition of the term community resilience; in most cases, the operational definition is constrained to how we want to measure and/or enhance it. In the context of our work, we consider that a resilient community would be able to transform its environment through purposeful collective action to cope effectively with adversity and learn from the experience for future preparedness [4]. The key nine elements that identify a community's resilience to disasters are [3]:

- local knowledge about a community's vulnerabilities, prevalent training and education practices, a community's shared belief in addressing hardships,
- networks and relationships leading to the community acting as a connected and cohesive entity during a disaster,
- communication that may relate to disaster-related language understandable by all residents, as well as existing information networks to disseminate anticipated risks prior to a disaster or crisis-related information during an ongoing event,
- health factors including both pre-existing health conditions within the community and existing mechanisms to deliver health services,
- governance/leadership factors responsible for allocating resources existing within the community to tackle a crisis, as well as the participation of residents in strategic planning, response, and recovery efforts,

- resources available to the community to tackle disasters, including natural, physical, human, financial and social resources, as well as the community's ability to utilize these resources in the event of a disaster,
- economic investment relating to the distribution of financial resources, as well as pertaining to economic programs for cost-effective interventions, and financial support for development of post-disaster infrastructure,
- disaster preparedness at a variety of societal levels (individual, family, and government),
- mental outlook reflecting the attitude of the community when faced with the uncertainty of a looming disaster, or in the aftermath of a disaster.

1.3. Scope

The DRAC is engaged in various research projects related to hurricane monitoring, fire detection, disaster risk analysis within the Great Plains region of United States (earthquake and flood susceptibility), understanding resilience of communities. We are also engaged in understanding the process of conducting trans-disciplinary research. Within this broader realm of DRAC research activities, this short paper provides an overview of data-driven hazard-detection technologies. In the forthcoming section, we provide an overview of the ongoing research, and discuss their connection to one or more of the aspects of resilience.

2. Event/Hazard Detection Technologies

2.1. Sensor infrastructure for disaster monitoring

Accurate understanding the scientific phenomenon behind the extreme weather events, both in terms of the anticipated geographical region it affects and the expected intensity of the event, is crucial for efficient disaster management, including timely evacuation and distribution of resources for relief operations. Modern forecasting systems for extreme weather events rely on data collected by a variety of different sensors. Usually, the sensor data is obtained from terrestrial, airborne, or orbiting sensors. The terrestrial sensors are usually limited by their range, while the airborne sensors are limited by the number of missions that can be conducted during the event as well as by how close the aircraft can fly to where the event is occurring. Owing to their strategic location in space, orbiting sensors often are the first to observe a disaster (such as a hurricane or a wildfire); however, the current in-space sensor infrastructure in Low-Earth orbits (less than 2000 km altitude) does not allow continuous coverage of geographical regions. Satellites in geosynchronous orbit (35,786 km altitude) have a continuous coverage over a specific geographic region; however, their location far away from the surface of the Earth limits the capabilities of the onboard sensors in understanding the three-dimensional structure of the event. Recent advents in miniaturization of sensor technologies that can be incorporated within nano-satellites or drones, deployed in large numbers can fill the gaps in current-day sensing needs and facilitate early disaster management operations. For instance, the planned FireSat constellation is envisioned to have 200 orbiting sensors for global wildfire coverage.

At DRAC, we have been working on designs of orbiting sensors that can meet the sensor data requirements of modern hurricane forecasting systems such as NOAA's FV3. The designed sensor system leverages relatively low-cost 6U CubeSat platform (small satellites of size 30 cm × 20 cm × 10 cm) to provide coverage over data-starved regions such as the Atlantic warm pool region where hurricanes originate [5]. Such designs help gather sensor data that has the potential in improving accuracy of early forecasts of hurricanes, thereby providing higher lead times for planning disaster relief operations. Even in regions where there is existing sensor infrastructure, such CubeSat-based sensor constellations can help reducing modeling errors and improve forecasts. One of the key areas of improvement is the prediction of intensity of the hurricanes, and our work related to CubeSat formation design specifically address this issue by enabling sensor data collection related to the three-dimensional structure of the hurricanes [6]. Orbital perturbations affect the satellite's position in orbit, and thereby the coverage it provides; hence, we also designed maneuver plans to maintain requisite coverage requirements [7]. Future work will focus on data-driven sensing to provide coverage over vulnerable communities.

2.2. Machine-learning enabled hazard detection and damage assessment

Advances in the field of artificial intelligence presents new opportunities for the detection of a hazardous event as well as estimation of damage caused by the hazard. One aspect of our work at DRAC focuses on the detection of fire and smoke from digital imagery using deep learning models. We have utilized multi-spectral deep learning models to analyze publicly available datasets and detect smoke or fire. We refer interested readers to Reference [8] (also presented at the workshop) for the details of this research. Our current focus is on lightweight machine learning models that can be deployed on small platforms of limited computational capabilities. The capability to identify such hazardous event on such platforms located closer to the event significantly enhances the early detection of the hazard, thereby leading to early intervention and early communication of associated risks to affected communities in the vicinity. Another aspect of our work is to use deep learning models to analyze satellite images to classify structural damage in buildings in the aftermath of a disaster.

2.3. Social media as sensor platform

The abundance of smartphones in the modern society and the ever-increasing engagement of public in social media provides an opportunity to use social media as a source of data on potential hazards. Autonomous analysis of social media data can lead to rapid identification of situations where disaster relief operations need to be diverted to. To this end, an aspect of our research at DRAC focuses on the analysis of multi-modal social media data (text and images) from the CrisisMMD database using a multi-modal fusion technology. Interested readers can take a look at Reference [9] (also presented at the workshop) for details on the technology and the results obtained.

3. Conclusion

Within the overall activities currently being pursued at the Disaster Resilience Analytics Center (DRAC), this paper focuses on research related to the detection of a hazardous event, namely, sensor placements using CubeSats to provide spatial and temporal resolution of data expected by modern modern weather forecasting systems, and analysis of data (from sensors or social media) using deep learning models to detect hazards. Such data-driven hazard detection can improve the efficiency of disaster relief operations. Availability of such technologies to a community can help improve their resilience in terms of providing additional resources to obtain information about anticipated hazards as well as improving disaster preparedness.

Acknowledgments

The author acknowledges the contributions of his colleagues to DRAC research: Dr. Mara Alagic (College of Applied Studies); Drs. Rajiv Bagai, Ajita Rattani and Kaushik Sinha (College of Engineering); Drs. Zelalem Demissie, Terrance Figy and Glyn Rimmington (Liberal Arts and Science); Dr. Atul Rai (School of Business); Drs. Aaron Bowen, Nathan Filbert, Meghann Kuhlman, Ethan Lindsay, Susan Matveyeva, Maria Sclafani (University Libraries). The author also acknowledges Dr. Jay Golden, former WSU President, for kick-starting the Convergent Science Initiative at WSU.

References

[1] Anonymous, UNDRR homepage, https://www.undrr.org/terminology/disaster, 2022. (Last accessed May 18).

[2] Anonymous, Summary stats, https://www.ncei.noaa.gov/access/billions/summary-stats#temporal-comparison-stats, 2022. (Last Accessed July 26).

[3] S. Patel, M. Rogers, R. Amlot, G. Rubin, What do we mean by 'community resilience'? a systematic literature review of how it is defined in the literature, PLOS Currents: Disasters (2017).

[4] R. Pfefferbaum, B. Pfefferbaum, R. Horn, The communities advancing resilience toolkit (cart): An intervention to build community resilience to disasters, Journal of Public Health Management and Practice 19 (2016) 250–258.

[5] P. Chadalavada, A. Dutta, Regional cubesat constellation design to monitor hurricanes, IEEE Transactions on Geoscience and Remote Sensing 60 (2021) 1–8.

[6] P. Chadalavada, A. Dutta, Cubesat formations for monitoring hurricanes, in: IEEE Aerospace Conference, IEEE, 2022.

[7] P. Chadalavada, A. Dutta, Coverage characteristics of hurricane monitoring cubesat constellationsunder orbital perturbations, in: AAS/AIAA Space Flight Mechanics Meeting (AIAA Scitech Forum), AIAA, San Diego, CA, 2022.

[8] S. Haridasan, A. Rattani, Z. Demissie, A. Dutta, Multispectral deep learning models for wildfiredetection, in: International Workshop on Data-driven Resilience Research, Leipzeig, Germany, 2022.

[9] S. Kotha, S. Haridasan, A. Rattani, A. Bowen, G. Rimmington, A. Dutta, Multimodal combination of text and image tweetsfor disaster response assessment, in: International Workshop on Data-driven Resilience Research, Leipzeig, Germany, 2022.