A Review on Applications of Big Data for Disaster Management

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***Abstract*—The term "disaster management" comprises both natural and man-made disasters. Highly pervaded with various types of sensors, our environment generates large amounts of data. Thus, big data applications in the field of disaster management should adopt a modular view, going from a component to nation scale. Current research trends mainly aim at integrating component, building, neighborhood and city levels, neglecting the region level for managing disasters. Current research on big data mainly address smart buildings and smart grids, notably in the following areas: energy waste management, prediction and planning of power generation needs, improved comfort, usability and endurance based on the integration of energy consumption data, environmental conditions and levels of occupancy. This paper aims presenting a systematic literature review on the applications of big data in disaster management. The paper will first presents the visual definition of disaster management and describes big data; it will then illustrate the findings and gives future recommendations after a systematic literature review.**

Keywords— Disaster management, big data, disasters, sensor data

I. INTRODUCTION

Effective management as well as monitoring of disasters is a global challenge [1]. All communities are vulnerable to disasters, both natural and man-made events [2]. A disaster is defined as a situation, which overwhelms local capacity, necessitating a request to national or international level for external help or an unforeseen and often sudden event that causes great damage, destruction and human suffering [3]. Disasters may be due to floods, fires, hurricanes, storms, oil & chemical spills, terrorist attacks, nuclear accidents or any other kind of meteorological or man-made events [4]. The economic impact of a disaster consists of direct consequences on the local economy (e.g., damage to infrastructure, crops, housing) and indirect consequences (e.g., loss of revenues, unemployment, and market destabilization) [5]. Regardless of numerous efforts by safety professionals and government agencies, disasters continue to occur and number of deaths remained high throughout the last years as shown in Figure 1 [6].

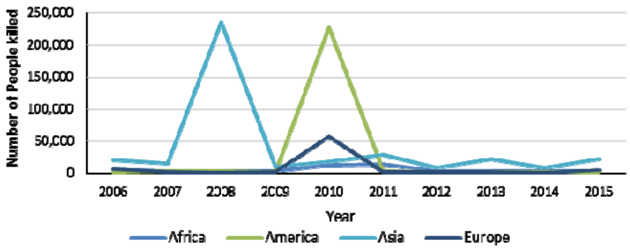

Fig. 1. Total number of people reported killed, by continent and by year (2006-2015) [6]

The vast variety of data sources present in times of a disaster creates a need for integration and aggregation of data and to make effective visualizations from it [7-9].

The storage and processing of large volumes of disaster data are perhaps the biggest challenges to be faced by civil defense, police, fire departments, public health and other government organizations managing disasters. It is very crucial for these organizations to get processed real-time disaster data as quick as possible in order to react and coordinate efficiently. Big data tools and techniques can assist disaster management officials to optimize decision-making procedures [10]. Even after the occurrence of a disaster, the organizations have to make future plans to mitigate the effects of disasters. But effective planning and management hugely depends on the quality as well as quantity of the data available [11]. Managed and efficiently shored datasets will not only empower decision-makers to make accurate assessment during a disaster but also help to take suitable actions for effective disaster response and recovery.

This paper aims at presenting a systematic literature review on the applications of big data in disaster management. The paper presents a visual definition of disaster management, describes big data and illustrates the findings from the systematic literature review. The paper is organized as follows: in section 2, background of disaster management and big data is described. In section 3, applications of big data for disaster management are presented. Section 4, is based on the discussion and conclusion along with future recommendations are discussed in section 5.

II. BACKGROUND

A. Disaster management

Disaster management is defined as 'the integration of all activities required to build, sustain and improve the capabilities to prepare for, respond to, recover from, or mitigate against a disaster'[12]. These four activities focus on risk management (prevention, preparedness) and crisis management (response and recovery) comprise the disaster management cycle as mentioned in Figure 2 [13]. These activities are not independent and sequential; indeed response and recovery phases initiate instantaneously, whereas populations have different long-term or short-term recovery operations can go on for days to months. Moreover, public health and economic recovery processes can take years or beyond that. The ultimate success of response and recovery activities are influenced by the data collected during the preparedness and prevention phases.

Fig. 2. Phases of disaster management cycle

Disaster management is a systematic process with primary aim to reduce the negative consequences and effect of disasters, hence safeguarding people and social infrastructure [7]. Disaster responsive is one of the most important phases of disaster management and aim at providing immediate help to maintain life and support the morale of the affected population. In order to improve disaster responsive, it is important throughout the world to increase knowledge of disaster management. The entire above objective may be facilitated by incorporating big data systems to process and store real-time voluminous disaster data with reduced time and cost for timely decision making [8].

B. Big data

Big data is characterized by data having at least four dimensions that are "data volume", "data velocity", "data variety" and "data veracity" [14]. In addition to these 4Vs, the most important is the "data value", which measures the usefulness of data. Big data paradigm consists of data management tools and techniques for storage, processing and security of data [15]. It becomes a complex process when data originating from different sources are used for decision-making. The main objective of big data management is to enhance data value and accessibility for decision-making. Big data paradigm can be divided into four major application areas as mentioned in Table 1: (1) big data methods, which deals with the collection of data to uncover hidden trends and patterns, (2) big data storage, which offers database management systems to store data at reduced cost, (3) big data processing, which provides platforms to do processing on a cloud and (4) representation, which offers software to make dashboards and visualizations based on real-time data [16-19].

TABLE I. BIG DATA PARADIGM

Area	Subarea	Description
Methods	**Data mining**	Process to explore large amount of data to find meaningful patterns and rules. E.g. Mahout is a framework for building data mining algorithms.
	Machine learning	An area of Artificial Intelligence (AI), used to discover knowledge and make intelligent decisions. Machine learning algorithms can be supervised, unsupervised, and semi-supervised. E.g. Spark and Storm tools are used for machine learning.
	Statistical analysis	Deals with the collection, analysis, interpretation, presentation and organization of data. E.g. SPSS software and R studio is used to perform statistics.
	Analytical tools	Examines raw data to uncover hidden patterns, correlations and insights. E.g. Spark
Storage	**Data warehouses**	A large data store accumulated from a wide range of sources within an organization and used for decision-making. E.g. Apache Tajo is a data warehouse solution built on Hadoop.
	NoSQL databases	A non-relational, largely distributed database that enables ad-hoc, fast organization and analysis. E.g. Column stores (Cassandra and HBase) and Document stores (MongoDb).
	In memory database	Primarily relies on main memory for data storage.
Processing	**Hadoop engines**	Open source Java Framework technology to store and process big data at less cost with high degree of fault tolerance and high scalability.
	Real-time analytics	It refers to a level of responsiveness that a system process and make useful insights out of it as immediate or nearly immediate upon receiving. E.g. Storm and Informatica
	Cloud sourcing	Outsourcing of IT resources to reduce costs and get access to technological expertise with fewer resources.
Representation	**Visualizations**	It provides at-a-glance views of key performance indicators for a particular objective. E.g. Tableau software is used to make dashboards based on real-time data, Google charts, etc.

Hadoop is one of the major components of the big data paradigm [20]. It is an open source framework allows distributed storage, processing and analysis of large datasets. Hadoop ecosystem consists of MapReduce, Hadoop Distributed File System (HDFS), Hive, HBase (Hadoop DataBase), Zookeeper, Mahout, Sqoop, Pig, Oozie, Flume and Ambari [21, 22]. Hadoop ecosystem is good for large sequential batch processing. In addition, Spark an open-source cluster-computing framework is efficient for interactive, real-time and parallel processing [23]. NoSQL databases have also gained popularity in the recent years for non-relational data storage solutions [24]. NoSQL databases can be divided into key-value stores, document Stores and column stores [25]. These databases are good for in-memory computing and used for data analytics [25, 26]. The application of cloud computing technologies has also increased in recent years, but hybrid cloud integration and development of integrated information management systems remain as important challenges that needs to be addressed.

III. Big Data applications for disaster management

The literature search for the review process on big data applications for disaster management applications is conducted using research databases, including Elsevier, IEEE explore, ACM digital library and Science direct. In addition, Google Scholar is used to supplement this process. The search was done from the research articles published from 2007 until 2017. For literature searches, the following keywords and their combinations were employed: ‘big data techniques’, ‘disaster management’, ‘real time systems’ and “Internet of Things (IoTs)” in the searching fields of abstract, title and keywords. Conference and journal papers addressing the big data technology applications in disaster management and monitoring sector were identified by excluding the technical reports as the focus of this review process was on research papers. Based on the collected literature, we identified the most relevant applications of big data for disaster management and mentioned their different datasets, technologies used with findings in a tabular form as mentioned in Table 2.

Big data generated from geo-informatics and remote sensing platforms can contribute to early warning systems for disasters. Geographical Information Systems (GIS), Global Positioning Systems (GPS) and environmental monitoring sensors with cloud services have a potential to predict disasters such as snowmelt floods [27] and earthquakes [28]. Geo-informatics information along with transportation network data can benefit to understand human mobility patterns during disasters [29] whereas, social media (e.g. Twitter) offers autonomously distribution of disaster awareness [30, 31] and can provides near to real time information of the occurrence of disasters [32]. The seamless integration of different data streams, along with the processing paradigms such as Hadoop ecosystem can support data processing and storage for effective disaster preparedness. A multi-sourced social media data can also be used to track hurricanes.

Plotting different type of geo-spatial maps can help in the development of effective strategies and contribute to minimize the potential effects of disasters. Research [33 - 36] provides the implementation of Hadoop architecture for the disaster data collection and surveillance system for disaster response and prevention. Efforts are not only made for big data processing and storage but also on reducing the execution time to query disaster data for fast decision making [34]. In addition, research [37] envisions creating large-scale events venue 3D simulation scenarios for simulating emergency situations such as fire and blasts. As large scale events covers large venues that consists of many people and traffic offer big datasets to generate interactive 3D models for simulating disaster situations. Moreover, research [38] highlights the significance of big data analytics to predict occurrences of the floods. The designed system is very limited in data sourcing and by incorporating more datasets and variables; it can be an efficient early warning system for flood management. However, to implement a fully integrated disaster information management system, integration of datasets along with the providing the access to information through a web based system to agencies managing disasters is most crucial to enable effective decision making.

IV. Discussion

There is a variety of big data available for each phase of the disaster management. The most important challenge is to understand how to link different datasets with different kinds of disasters. As it is apparent from Table 2 that types of datasets are kept limited and the potential of big data technology has not been fully explored for disaster management. Not all big data is public and freely available. Facebook data can be accessed using its open Application Programming Interface (API), however Twitter data can be expensive to use. To access call detail records of mobile subscribers, a financial agreement is required with a Telco. In addition, some satellite data is free (Landsat, SRTM etc.) and other needs to be purchased (LiDar data, GeoEye, etc.). Moreover, aerial nadir, thermal and oblique Imagery data also can be incorporated for geospatial data analysis that can helps in the identification of people in the affected areas. In addition, financial datasets constitutes information of financial transactions (e.g. credit/debit cards etc.) can also be used to recognize population movements and behavioral response before or after disasters. Furthermore, transportation datasets acquired from vehicles equipped with GPS systems can be used for assessment of damage caused by the disaster. User deployed wireless sensor networks and Radio Identification (RFID) systems also play a vital role in environmental data generation and tracking of people. However, the openness of wireless channel in wireless mobile communication provides opportunities to individuals for malicious activities with wireless channel such as inserting, modifying or even deleting information to deceive disaster system. Therefore network security threats and vulnerabilities should also be considered as these not yet taken into account in the existing disaster management applications. Incorporating multi-sourced heterogeneous data from different data acquisition networks offers to derive information that can help to anticipate multiple disasters and recognizing the dangers.

Big data paradigm is complex in nature and it raises challenges related to protection of personal information and privacy. As big data constitutes an immense volume of information of people and at least some part of this data is confidential in nature. Such information gets more exposed when processed in big data paradigm. Therefore, it’s important to protect individuals’ identifications and efforts should be put to anonymize the collected datasets. After data is aggregated and anonymized, an appropriate big data technology should be used for processing and storing the data. Open source and cloud based solutions (Hadoop, Spark etc.) have already reduced some of the storage and processing limitations to some extent[17].

TABLE II. BIG DATA APPLICATIONS IN DISASTER MANAGEMENT

Case	Application of integrated information system for snowmelt flood early-warnings [27]	Implementation of an autonomous emergency warning system based on cloud servers and messaging module [28]	To design a simulator for human emergency mobility following disasters [29]	Development of a generic Knowledge as a Service (KaaS) framework for disaster cloud data management [30]	Real-time monitoring of social big data for disaster management [31]	Development of a disaster surveillance system based on Zigbee and cloud services [32]
Disaster type	Floods	Earthquakes and fire	Earthquakes	-	Flood, fire and explosions	-
Disaster phases	Preparedness	Preparedness	Preparedness and Response	Response	Response	Preparedness and Response
Data	Geo-informatics and sensor data	Earth quake and gas sensors data	GPS records of 1.6 million users throughout Japan from 1 August 2010 to 31 July 2013, news reporting data and transportation network data	Social media data (blogs and tweets), sensor readings, incident reports	Social media data (tweets)	Temperature readings collected from seven different sensors simultaneously for ten times
Findings	Presented an integrated approach based on geo-informatics, Internet of Things (IoT) and cloud services.	Proposed prototype system provides a useful awareness against disasters by autonomously distribution of warnings by twitter.	Simulated and validated the general model of human emergency mobility to be predictable using the experimental results.	Stored huge disaster related data from heterogeneous sources and facilitated searches by supporting their interoperability and integration.	Designed system crawls Twitter data, analyses the disaster-related tweets in real time and displays disaster trends in a map.	Zigbee based congestion control model is built for real-time monitoring of disasters and non-real time predication of disasters.
Key technologies used	GIS, Global Positioning System(GPS)	GPS, cloud server, Arduino and Mysql databases	-	Combination of relational and NoSQL databases	GPS and document databases	Hadoop and Zigbee

Case	Synthesizing multi-sourced data to perform statistical analysis for disaster management [33]	Design of disaster collection and analysis system using crowd sensing and beacon based ad-hoc routing [34]	To improve query performance in a geospatial semantic web for disaster response [35]	Smog disaster analysis based on social media and device data on the Web [36]	Conceptual establishment of big data cognition for city emergency rescue [37]	Development of an early warning system based on big data analytics for flood information management [38]
Disaster type	Hurricanes	-	-	Smog	Fire	Floods
Disaster phases	Response	Preparedness	Response	Prevention	Response	Preparedness
Data	Geographical and social media data (Twitter) collected from 38,224 tweets for analysis	User based location data collected from users' mobile devices	Geospatial data collected from 54 schools and 3,449 streets	Social web data randomly collected from 100,000 geographic position marked tweets	Population distribution, geographical, video and socio-economic data	Taken highest reading of rainfall and water level of rivers of the day for 3 years (2012, 2013, and 2014)
Findings	A framework is presented to mitigate the potential effects, respond and coordinate efficiently during disasters.	A system is designed to collect real-time disaster data and generates fast local evacuation alert for users.	Proposed approach reduces individual spatial query execution time in disaster response applications.	Proposed framework helps to provide guidance on people's behavior and government's strategy designs for smog disaster mitigation.	A large-scale events venue 3D simulation scenarios are generated to simulate emergency situations to improve the auxiliary decision-making ability during a disaster.	A weak level of relationship between the rainfall and water level of rivers is identified using an algorithm for the occurrence of floods.
Key technologies used	GIS, Apache Hive, Hadoop and Mahout, R	Hadoop, HTML5	Map-Reduce	Hive and Storm	-	Semantic networks and ontologies

Application of big data systems over here is to leverage techniques from artificial intelligence (AI) and machine learning (ML) concepts to understand, explore correlations and draw findings from the disaster related data that has been collected from different acquisition platforms such as Internet, mobile phones, sensors, RFID systems etc. It will help for timely humanitarian response to different disasters. In addition, using geospatial datasets acquired from geo-informatics systems along with big data paradigm can further provide location based services to avoid hazardous situations. It will also benefit in the identification of regions which need the most urgent attention from the disaster administrators and government agencies. Furthermore analysis from processed disasters information can help to identify the most effective strategies to respond future disasters.

V. CONCLUSION AND FUTURE WORKS

Effective disaster management is a global challenge. The potential and utility of big data paradigm is growing for disaster management as the number and access to different datasets is expanding rapidly. This paper presents a review of big data applications in disaster management. It gives an overview of what kind of data is used in existing systems for managing disasters, which specific phases of disaster management a system is targeting to and what are the enabling technologies that have been used along with big data technology to supplement disaster management decision processes. After a systematic review, it has been observed that big data research remains in its developing phase into existing workflows and practices for disaster information management. There exists a major gap particularly in seamless integration of different data sources as number of datasets kept limited in stated applications. The main issue in big data management for monitoring disasters that has been identified is to ensure data consistency, accuracy and completeness for decision making processes. As data collected from various heterogeneous sources at the time of occurrence of disasters is highly susceptible to noise. Therefore, different data preprocessing techniques should be incorporated to remove data inconsistencies. Furthermore, there is a need to investigate data mining challenges as well for disaster management. Efficient data mining methods will help to discover various associations, correlations and trend analysis in order to reduce the future reoccurrences of disasters. Finally, security as well as privacy issues in data transmission and storage also need to be under constant investigation to ensure the authenticity of disaster data while keeping the confidentiality of people`s sensitive information.

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