Prevention of disasters supported on the Internet of Things and Early Warning Systems

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Abstract. Climate change has brought with it the increased risk of occurrence of natural disasters that generate a high economic and social detriment and even the loss of human lives, for this reason in the last decades governments have been worried with finding more efficient ways to prevent or mitigate the impact of natural disasters can cause, in this way early warning systems emerge. This work exposes the evolution and concepts related to Early Warning Systems (EWS) and also develops analysis about the SAT implemented to prevent the three most common types of natural disasters: floods, earthquakes and epidemics. Therefore, the future trend of these EWS is also analyzed.

Keywords: Early Warning Systems, Natural Disaster, Flood, Earthquake, Epidemics.

1 Introduction

Natural disasters are catastrophes caused by natural phenomena (e.g., landslide, earthquake, tsunami, flood, forest fire and lightning) or by human intervention (e.g., industrial explosion, leakage in production of gas and terrorist attacks) [1], in a certain area. Generally these events take place in the vicinity of livelihoods, leaving loss of human lives and incalculable economic losses.
Floods, for example, are frequently repeated in several regions of the world due to natural phenomena such as hurricanes, seaquake, tsunamis and river overflows, which threaten to take everything in its path. Tsunamis are caused by tremors and earthquakes, another type of natural phenomenon. The tremors and earthquakes are the disturbances of the earth's crust [2], in addition the intensity of movement of earthquakes is more shocking than the intensity of movement of earthquakes and usually after an earthquake occur tremors appear in the form of aftershocks (replicas). Climate changes are also responsible for the emergence and spread of epidemics that can trigger states of emergency in different regions of the world. According to statistics, the global surface temperature has increased approximately 0.2 ° C per decade in the last 30 years [3]. The extreme behaviors of the climatic phenomenon are responsible for the appearance

of epidemics like Malaria, Dengue, Influenza, and Diarrhea among others that can be fatal, however is possible to minimize the damage resorting to different sciences and technologies.

In recent years, countries have made a great effort to find technological solutions that can face the contemporary challenge of climate change [4], paying more attention to real-time monitoring of disasters, which is why they have developed mechanisms for acquisition, transmission , processing, analysis and data management for the integration of Early Warning Systems [5]. Some proposals take advantage of the use of Big Data and Web 2.0 applications to issue early warnings, supported in the implementation of Internet of Things (IoT), wireless sensor networks, satellite mapping or radar monitoring.

The purpose of this article is to contrast the most relevant characteristics of the SATs developed to predict the three most common types of natural disasters (floods, earthquakes and epidemics), evaluating the most used and emerging technologies, how the input information is obtained, how the information is transmitted when the probability of a possible disaster is known and the possible causes of its occurrence.

2 Early Warning Systems

The importance of implementing a SAT lies in the fact of knowing in advance where and when, a threat can trigger potentially dangerous situations. According to the International Strategy for Disaster Reduction (UNISDR) [6], an early warning is defined as the provision of timely and effective information through identified institutions that allow individuals exposed to a threat to take action to avoid or reduce the risk and the preparation for an effective response. The SATs are systems that predict the proximity of events that can generate disasters and that, conjugated with risk management plans, become significant and indispensable measures for the effectiveness of an alert and the reduction of damages.

The first concept of Early Warning System known to date was introduced by Dr. Cooper on November 3, 1868 [7], where he proposes an Alert System based on campaigns and other resources that were available at that time. Since then, different systems have been developed, leading to complex modeling for data management and basic systems, taking advantage of resources such as the Internet and social networks.

A complete and effective early warning system comprises four interrelated elements [8] that work collectively and the failure of one of them would cause the total failure of the system, diverting its final purpose, as presented below:

- *Risk knowledge*
- *Monitoring and warning service*
- *Dissemination and communication*
- *Responsiveness*

A disaster monitoring and early warning system needs to solve three problems: "what to detect, how to transmit and how to use" [5], and gives rise to a fourth problem: "what to transmit". The structuring of the general architecture of an early warning system is divided into four parts that include methods, technologies, managers and protocols as presented below:

- *Input information and detection of anomalies:* The focus of this first level of architecture is based on "what to detect" and "how to detect".
- *Transmission networks:* The data obtained is reported to analysis and evaluation centers, where specialists predict the probability of a destructive event. These transmissions are made through satellite networks and computerized systems, or through the use of communication media such as radios, telephones and any means that allows the rapid and safe transmission of information to generate responses that allow action to be taken on time.
- *Data monitoring and analysis center:* Once the data has been transmitted, the question to be answered is "how to use" the content received. The expert staff is in charge of evaluating the data and establishing the probability of the event. These data can be analyzed through calculations, technological equipment and specialized software for forecasts that allow to consider the level of risk to which an exposed community.
- *Definition of alert situation:* The forecasts generated in part 3 of this architecture provide information on the potential damage and the type of alert that the competent authorities must issue. At a global level, four warning colors are known that indicate the level of risk and the protocols to follow: green alert, yellow alert, orange alert and red alert; meaning the green color a normal state of the behavior of the phenomenon and the red color the inevitable arrival of the event.

In the development of an Early Warning System, the approach that is intended to be given at each stage is decisive; whether the objective is prediction, detection or warning, if its focus is the model, systems or infrastructure; the extent of human intervention required; and its input data [9]. In addition, the SATs must maintain a balance between their levels of complexity, they cannot be too simple given that they lose reliability, nor so complex that they are not economically viable.

2.1 Early Warning System for Flooding

Floods are a constant threat globally and develop so quickly that they sometimes do not allow the competent agencies to act, becoming the type of disaster with the highest mortality rates in recent decades, as evidenced by the tsunami of the Indian Ocean in December 2004, which killed 220,000 people and left 1.5 million more homeless [10], or the historical records of the city of Bangladesh, where only floods account for almost 90% of natural disasters in the country and every year, at least 20% of the area of Bangladesh is flooded leaving losses of approximately US $ 1,500 million [11] where the agricultural sector and the poorest communities are the most affected.

In recent years, a large number of projects supported in IoT, aimed at the development of flood protection systems have been initialized around the world [12]. These warning systems are mostly localized, custom designed and use local computer resources [11] making comparison between statistics and prototypes difficult, however, standardization in the procedures for evaluating data, systems and flood risks is having place slowly at the national level in many countries [13]. Globally, the Dartmouth Flood Observatory [14] conducts global monitoring by providing the most open access information, facilitates the downloading of satellite images of major floods around the world, but does not issue early warnings, nor does it provide precipitation data that they could alert about floods before the events, nor diagnose the flood conditions. The Global Flood Warning System (GFAS) [15] publishes free access information on its website, such as precipitation probability estimates, useful information for prediction and flood warning.

State-of-the-art flood warning systems such as the Bandon Flood Early Warning System [16] use meteorological data, water levels and, optionally, remote data from satellite monitoring as input sources [12]. Orbital remote sensing (Advanced scanning microradiometer) is used in the Dartmouth Flood Observatory [10] and its set of satellite microwave sensors are used to visualize large floods in the world and monitor surface increases of the water of the floodplain.

The input technology of the SAT is generally based on remote systems (radar or satellite), sensor chains, wireless sensors or different mixtures of these that allow having the ability to generate reliable forecasts. One of the most difficult aspects of flood forecasting is the accurate estimation of rainfall, which is commonly done with rain gauges [17]. The use of remote sensors, such as radars, that allow the sampling of a larger area in short periods, has increased in recent years and provides information on the movements and the evolution of rainfall allowing the warning to be issued in advance. [18] However, most of the precipitation forecasts present great errors of accuracy and and the level of uncertainty grows due to the rapid action of hydrological phenomena.

The FLOODsite project [19] developed a set of models for flood risk analysis and management methodologies, where the main input parameter for the simulations was water elevation data. Many models for flood prediction are based on observing rainfall and / or monitoring parameters such as sea surface temperature, air humidity, wind speed and rainfall estimates. According to Shahzad and Plate in 2014 [20], the different methods for predicting floods can be grouped as follows: 1) Direct prediction methods using precipitation models and discharge curves; 2) Methods with complex hydrological models that demand very long time series; they generally incorporate uncertainty and use the Monte Carlo method to calculate deviations from real data and forecasts; 3) Methods that do not require models and that, based on the initial conditions, hydrological maps are generated using historical data; 4) Methods used in large rivers and use regression analysis for the measurement of upstream and downstream.

2.2 Early Warning Systems for Earthquakes

More than one million earthquakes occur in the world each year with an average of approximately two per minute [20], reporting more than 530,000 deaths from earthquakes in the last 25 years [21]. Barpak, district of Gorkha, was the epicenter of the earthquake of April 25, 2015 in Nepal that ended the lives of more than 8622 people with a moment magnitude of 7.8. On May 12 of the same year, a second earthquake occurred in Chilankha, district of Dolakha, with a magnitude of 7.3 [22]. In the past, the world witnessed great catastrophes with high numbers of human losses, as shown in Table 1, [21] leaving infrastructure problems, fires, floods and large agricultural and economic losses:

Table 1. Deathly victims of earthquakes in Mexico, Colombia, Iran and India

Epicenter	Year	Deathly victims
Mexico	1985	10.000
Colombia	1988	25.000
Iran	1990	40.000
India	1993	10.000

Earthquakes are due to a sudden release of accumulated tensions around faults in the earth's crust. This energy is released through seismic waves that travel from the area of origin, which causes the ground to shake. When an earthquake occurs, two seismic waves (P and S) are created that propagate outward from the hypocenter in a spherical pattern [23]. The S wave, or secondary wave, is the most powerful and destructive, therefore, its early detection is important. There has always been considerable uncertainty regarding the physical aspects that precede an earthquake. The natural processes that modulate the occurrence of earthquakes include changes in tectonic stress, migration of fluids in the crust, tides of the Earth, ice on the surface and snow load, heavy rainfall, changes in atmospheric pressure, sediment discharge and loss of groundwater [24]; In most cases, such effects probably go unnoticed, nevertheless, a clear coincidence has been evidenced between the seismic events that occurred and the anthropogenic and industrial intervention in these places.

More and more countries are betting on the development of SAT for earthquakes. Japan, France, Germany and South Korea have established the system of seismic monitoring and early warning, in order to guarantee the safety of the high-speed train [25], in addition, scientists around the world have endeavored in different ways for the detection of seismic events, being successful to some extent, therefore, earthquakes can be detected before the event occurs, but it would not allow sufficient time to proceed with the safety and disaster prevention protocols [26]. Early warnings for earthquakes are classified into two types according to the different alarm modes [27]: P wave warning and seismic ground threshold warning. The Wave Warning generally provides information a few tens of seconds before the event occurs, however, they are capable of generating false alarms. The seismic earthquake threshold warning on land rarely generates false alarms but it requires a lot of time for the activation of the alarms by means of the S wave.

Since 1950, the urgency of creating a SAT for earthquake monitoring was conceived, where the first developments were based on the observation of strong movement, for example, SMAC [28], the first strong movement seismograph in Japan developed in 1953. It was in 1985 when the term UrEDAS [29] (Urgent Earthquake Detection and Alarm System) was introduced, the first P-wave alarm system in real time in practical use in the world which is capable of processing digitalized waveforms step by step without It has the capacity to detect the P and S waves, the epicenter through the P wave, the magnitude of the earthquake and the distance and depth of the epicenter [30].

Subsequently, under the need to estimate the expected destructiveness of the earthquake, the Compact UrEDAS [30] was developed, a system that can emit the alarm immediately (almost a second after the detection of P wave) depending on the danger of movement seismic detected from the acceleration vector and the velocity vector; and also emit the alarm with an S wave, the most destructive; that is, Compact UrEDAS acts directly from the earthquake movement, not from the parameters of the earthquake such as UrEDAS. The UrEDAS system was so successful that it was converted to civilian use throughout Japan, where the Japanese Meteorological Agency (JMA) launched the Earthquake Early Warning (EEW) [31], which adds a series of mandatory alerts on TV and radio generated automatically, no matter what is being transmitted, as well as a system of cell phone alerts that goes off immediately and all inhabitants are notified.

In Mexico, the Seismic Warning System (Sasmex) [32], which began operating in 1988, activates a seismic alarm in the more than 8,000 speakers in Mexico City when the system's sensors detect earthquakes of magnitude greater than 6. The Sasmex now has 97 sensors on the Mexican Pacific coast, alerting 6 Mexican cities.

Currently, the possible causes that generate seismic events are known, but it has not been possible to predict these catastrophes well in advance. The scope of modern warning systems that include sensors, seismographs and immediate communication systems only reach record predictions of up to one minute prior to the event.

2.3 Early Warning Systems for Epidemics

Climate changes and their uncertainty affect people's health on a large scale, one of the pillars in the social development of each country. Health indicators are key components of human development indices, for example, in the United Nations Millennium Development Goals (MDGs) [33], where the quality of health and health are measured. Environment to assess progress towards global sustainable development. Many of the most common infectious diseases, and particularly those transmitted by insects, are highly sensitive to climatic variation [34]. Much of the literature addresses the factorial and potential impacts of climate change on many types of infectious diseases, including those transmitted by vectors, by water, air and food. Malaria is transmitted by mosquitoes and kills almost 600,000 people each year, especially African children under the age of five [35]. Other epidemics such as Dengue, Zika, Chikungunya, Influenza, Malaria, Smallpox and Diarrhea are also epidemics caused by climate disorders.

An epidemic is the manifestation of a disease in a significant number of people or living beings in a given space and time. When the disease reaches its global spread, it is known according to the World Health Organization (WHO) as a pandemic [36], where it assumes that the majority of living beings are not immunologically capable of combating it. Several SATs have been developed worldwide for the prediction and control of propagation of epidemics, some of them try to predict epidemics before the transmission activity begins, by means of the use of climatic variables supported in IoT, that predict the transmission potential [37] . ProMED [38], an online epidemiological information system developed by the International Society for Infectious Diseases

(ISID) and the Pan American Association of Infectious Diseases (API), uses the Internet resource and issues real-time information on outbreak detection of diseases based on Data Mining and analysis of historical cases.

One of the techniques of early detection in the new era is the location of bio-agents (bacteria, toxins, viruses). Traditional methods of monitoring and detecting bio-agents include assays based on biochemical and immunological recognition, biomolecular techniques such as polymerase chain reaction (PCR) or cell culture [39]. These methods often require hours or days for their detection and allow the epidemic to spread freely. At present, methods such as the use of nanomaterials, due to their small characteristics, make possible the development of nanobiosensors. Thanks to the properties of Nanotechnology and the body's immunological processes, electrical and colorimetric detection systems have also been explored, such as photoluminescence, electrochemistry [40].

Daniel Bernoulli's research on the effect of smallpox inoculation on the 1760 propagation [41], led to the development and application of mathematical models to explain the spread of epidemics. The modeling of epidemic curves, for example, allows to evaluate their evolution in the environment and can be divided into three classes according to Brooks [42]:

- Estimate the number of people in several countries related to a disease, taking into account the proportions of the susceptible, infected and recovered population of the condition.
- Models based on agents that generate synthetic crops and create complex patterns of interaction and behavior of diseases in synthetic humans.
- Parametric statistical models (time series modeling tools) and include generalized linear models, Box-Jenkins analysis and autoregressive models of moving average.

The progress of Big Data during the last decade has allowed a mutual collaboration between the community, epidemiologists and Big Data specialists for the surveillance and control of diseases. Initiatives such as the Big Data to Knowledge (BD2K) project [42] launched in 2013 and developed by the National Institutes of Health (INS), support the research and development of instruments to accelerate the integration of Big Data and data science in biomedical research. On the other hand, Web 2.0 has generated great interest recently, as a possible means to spread alarms in the detection of outbreaks by epidemics [43], using data resources generated by some platforms such as Twitter, Google and Wikipedia.

3 Analysis and contrast of EWS

Most studies in each type of disaster center their research on small events, for example, on the temporal and local development of diseases and epidemics; and it is not for less, because the objective of these SATs is to prevent an epidemic from migrating to other continents and to complicate the control of its spread. In contrast, there are so many small tremors globally that the SAT does not bet on its detection, since they do not pose a great threat, therefore, systems are developed that are activated with earthquakes greater than 6 ° in the corresponding scale due to that are considered more destructive, because the purpose is that the system contributes to reduce the damage caused by this type of disaster.

One limitation in the prediction of floods, earthquakes and epidemics is the discrepancy of information between the different models in each type of disaster, given that there is no standardization for the acquisition of data and their analysis. It can be found then that two SATs for hydrological prediction in a specific point of the planet (one supported in IoT and another supported in satellite mapping system), can emit alerts with different emission times and precisions. However, Big Data is still the most used support in the SAT to contrast current conditions with events that occurred before.

Climate changes become the most appropriate explanation when trying to determine the causes of a natural disaster; cold and heat waves, winter and drought seasons, the greenhouse effect, etc., are often responsible for the annual mortality rates due to natural and meteorological phenomena, as well as the estimated economic and forest losses. However, demonstrations of these events are also evident in industrialized sectors or where mining and human intervention modify the natural characteristics of the land.

The SATs for earthquake prevention are simple and do not have technology that allows prognosis or early diagnosis due to rapid action. It is necessary that the functions of measurement, information processing and seismic disaster prevention are developed and operated automatically, since the rapid action of these events does not allow the detailed analysis of the input information. Several efforts have been made focused on the development of small and low-cost earthquake alarm systems as a support tool for disaster prevention, however, the urgency remains the short time between the issuance of the warning and the earthquake.

The trend in the use of IoT is evident in the three types of SAT for disaster prevention, which include specialized sensors and state-of-the-art technology which allow the evaluation of the characteristics of the environment and provide information capable of detecting the event and its possible causes, even though these SATs only work locally. However, some SATs around the world refrain from investing in these technologies and base their systems on the analysis of remote data information from satellite monitoring as input sources, provided by organizations with information open to the public such as NASA, GFAS and Dartmouth. Flood Observatory, ProMED, among others. These SATs have the ability to monitor large areas, but do not provide information on the possible causes of the event.

4 Future works

The orientation of future research focused on IoT is related to the reduction of sensor costs, the design of low energy consumption sensors [1], the extension of interoperability between sensors and information reception devices, advanced decision support systems and evaluations in real time, the appropriate selection of data mining algorithms [44] and intelligent disaster management systems supported on the Internet of Robotic Things [45], which can help find the victim in rescue operations.

The United Nations Organization mentions the possibility of building a globally complete EWS, based on existing systems, using observation networks, alert centers, modeling and forecasting capabilities, telecommunications networks and preparedness and response capabilities already existing.
The prospective in the investigation of new technological tendencies combined with Smart Cities can provide interesting tools of mitigation of damage by natural disaster and maintain the sustainable development standards of the big cities.

5 Conclusion

The development of new techniques that reduce the possibilities of loss of human lives, environmental and structural damage, has been the objective of SAT researchers throughout history. Tools such as the interconnection between devices with various functionalities (IoT), the management of data analysis and historical data (Big Data), the use of Web 2.0 and various artificial intelligence tools, are used for the issuance of early warnings and work synergistically with disaster management. Synthesizing the content of this document, the objective is to provide the foundations about the SAT for prevention of natural disasters that include input information, technologies used, data analysis models and the possible causes of occurrence of these events, which help to understand the importance of the contributions of research throughout history and the future direction of these, which prepare man for the natural challenges to which he will continue to face.

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