Research Challenges in Developing Multimedia Systems for Managing Emergency Situations

Mengfan Tang
Department of Computer Science
University of California, Irvine
mengfant@uci.edu

Siripen Pongpaichet
Department of Computer Science
University of California, Irvine
spongpai@ics.uci.edu

Ramesh Jain
Department of Computer Science
University of California, Irvine
jain@ics.uci.edu

ABSTRACT

With an increasing amount of diverse heterogeneous data and information, the methodology of multimedia analysis has become increasingly relevant in solving challenging societal problems such as managing emergency situations during disasters. Using cybernetic principles combined with multimedia technology, researchers can develop effective frameworks for using diverse multimedia (including traditional multimedia as well as diverse multimodal) data for situation recognition, and determining and communicating appropriate actions to people stranded during disasters. We present known issues in disaster management and then focus on emergency situations. We show that an emergency management problem is fundamentally a multimedia information assimilation problem for situation recognition and for connecting people's needs to available resources effectively, efficiently, and promptly. Major research challenges for managing emergency situations are identified and discussed. We also present a platform to assimilate heterogeneous data streams for intelligently detecting evolving environmental situations, and discuss the role of *multimedia micro-reports* as spontaneous participatory sensing data streams in emergency responses. Given enormous progress in concept recognition using machine learning in the last few years, situation recognition may be the next major challenge for learning approaches in multimedia contextual big data. The data needed for developing such approaches is now easily available on the Web and many challenging research problems in this area are ripe for exploration in order to positively impact our society during its most difficult times.

Keywords

Disaster; Situation recognition; Situation prediction; EventShop; Micro-reports;

1. INTRODUCTION

Disasters happen. And Disasters will always happen. We have to be ready for them, respond to them *efficiently*, *effectively*, and *promptly*, and then manage their long term consequences. Disasters such as floods, earthquakes, landslides, forest fires, tsunamis, hurricanes, terrorist bombings, Zika or similar epidemics, global warming, and air quality crisis cause huge damage in both human lives and property across the globe. Furthermore, a disaster sometimes reaches the stage when it becomes an *emergency*. During an emergency, lives are lost and property may be damaged. The right information, at the right time, at the right place, and to the right people minimizes the loss of life, property, and misery.

In this paper, we propose the use of multimedia for predicting emerging disastrous situations, identifying people's needs during disasters, and helping them during disasters. We believe that multimedia computing and communication systems have a pivotal role to play in disaster preparedness, help during disasters, and then in recovery afterward. Multimedia computing has evolved from basic audio and video applications in business and entertainment to using information from different multimodal sources for understanding and helping people and organizations. Researchers started paying attention to situation recognition and appropriate actions to help people in different novel applications [32]. Disaster management may benefit significantly from multimedia (including multimodal) information. More importantly, for the emerging broader multimedia community, disaster management in general and emergency response in particular may be a transformative research area.

Researchers from environmental science, social science, public health, computer science, and various disciplines put a lot of effort into better predicting the space, time, and severity of disasters for improving response and mitigation. Governments, NGOs, and other organizations concentrate on disaster management, appropriate information sharing and communication, analysis of citizens' needs, and disaster recovery planning. Large volumes of diverse data are being collected regularly by sensors, IoTs, social media, governmental reports, and citizen reports. The data is essentially multimedia big data, because of the volume, variety, and velocity [19].

We believe that people are the best sensors, people are the best responders, and people are the best actuators. Our approach to using multimedia for emergency response is based on using people equipped with mobile phones connected to multimedia disaster management systems, both for collecting real time in-situ information and receiving instructions for action at the right place. In this approach, multimedia data resulting in timely actionable information is the key.

MM '16, October 15-19, 2016, Amsterdam, Netherlands
© 2016 ACM. ISBN 978-1-4503-3603-1/16/10...$15.00
DOI: http://dx.doi.org/10.1145/2964284.2976761

In 2011, Thailand witnessed its worst flooding in more than half a century, causing severe damage to the country's economy, industrial sector, and society. Two-thirds of the country was declared as a disaster zone. This flood started in June and lasted until December. More than 4 million households and 13 million people were affected for over 6 months. The World Bank ranked it as the world's fourth costliest disaster as of 2011 [1]. People, companies, and disaster relief agencies could not make proper decisions in time because they received little information from authorities and any other sources. Even though there were lots of international movements, the aid was slow in reaching affected people because of the communication deficiencies. There was no good mechanism to identify where the needs were and where affected people were.

In this paper, we will use floods as a running example for emergency situations because of their common occurrence and disruptive effect on societies. Most issues discussed for floods are easily generalizable and adaptable to other emergency situations. We will discuss in more detail our multimodal approach that we apply to the Thai flood example in the above box.

A multimedia community has already developed powerful tools for personal media management, commerce, and entertainment. These were good research areas for early multimedia because the problems were not life critical, time sensitive, or inherently complex, but sill required intricate relationships among many heterogeneous media types. The multimedia community is now ready for new challenges. In this paper, we present research challenges in developing multimedia systems for predicting situations, projecting needed resources and its dissemination through people at the scene of disasters. Our goal is to introduce emergency responses to the multimedia community as the next challenging frontier for research and development in order to address life-critical problems our societies face. Many challenging problems that are central to multimedia computing are central to emergency response, but with different requirements. Moreover, emergent responses require a general framework that could be easily instantiated for specific applications. Also, though emergency response systems pull together many components, the research is well compartmentalized in many sub areas. It is easy to explore and evaluate subsystems using easily available past data. We explicitly list ten challenges for the multimedia research community.

We demonstrate our early ideas for building a multimedia emergency response as a Cyber-Physical-Social multimedia computing system. This system uses the EventShop platform [32], which allows heterogeneous geospatial data stream integration and assimilation for situation recognition by combining diverse data sources. In the proposed framework, disaster situation awareness can be enhanced using diverse data streams from sensors, IoTs, social media, and citizen reports. Improved situational awareness allows for applying contextually sensitive control actions. Participatory citizen reporting using micro-reports from emerging systems like Krumbs[1] provides a straightforward and effective way to report situations without citizens having to identify potential contacts for report sharing. This type of reporting also facilitates information sharing and collaboration between organizations and citizens to maintain and enhance their communications. We introduce what-if scenarios to aid decision makers in understanding the current and future state of disaster situations.

[1]www.krumbs.net

Figure 1: Three stages in the disaster management. Planning and recovery have different level of urgency than response.

2. CURRENT DISASTER MANAGEMENT RESEARCH

The term "Disaster Management" is commonly used to represent different phases of a disaster: planning, response, mitigation, and recovery. These phases were identified based on different operations that needed to be considered for dealing with disasters. From the perspective of multimedia technology, a disaster management system may comprise three phases as shown in Figure 1 and as discussed below.

- **Planning**: Planning includes preparations made to stop disasters from happening, and to plan response and rescue when they do happen. For example, evacuation plans in disasters are made and life supply necessities, such as food and water, are stocked. An important part of the planning is to send proper guidance to people during the disaster response stage. This guidance must be prepared such that it is delivered to people using the right media at the right time. During a flood, the system should inform and warn people before the flood hits them using their phones as well as public broadcast systems.
- **Response**: This is the most catastrophic stage, usually called emergency. In emergency response, actions are taken to save lives and prevent further damages. It puts prepared plans into action. Life saving responses usually require timely action. People should have access to the latest information in their vicinity. The best mechanism today is a dashboard on their smartphone that gives flood situations, road conditions, shelters, food availability, and even their friend and family situation. All this information should be prepared using various multimodal data sources including people reports. This may be one of the most challenging areas for multimedia, where semantics of different data streams, multi-granularity, and uncertainty

of data must be overcome to build current and predictive situation maps. This phase is the main theme of this paper.

- **Recovery**: Recovery includes actions taken to get back to normal or safe situations after disasters. It may require months until public facilities such as roads, schools and hospitals can function well. Recovery of human health conditions may take even longer. During this phase, the system has to assimilate information from sensors as well as from people about the state of the infrastructure that needs to be rebuilt or is being rebuilt. More importantly, information about both the material and emotional impact on people needs to be managed properly. This will also involve not only gathering information from various sensors, databases, and people, but also building current recovery situation maps that could be used for planning and prioritizing future planning, response, and recovery efforts.

Sensor networks, camera networks, and IoTs are increasingly used for collecting data, monitoring, and predicting natural disasters. Data is continuously used by geospatial models to predict time and locations of happenings or movements of disasters. There have been a lot of studies focused on developing more accurate models, and various efforts in building sensor networks for data collection [18]. The damage of disasters depends on the distance from the disaster and the potential area. To estimate the damage accurately, historical data needs to be efficiently stored, mined, and studied. [23] and [35] propose a tree-based model and use hydrological data, remote sensing data, meteorological data, and rainfall data to assess the damage from floods. [8] uses time series volcano observation data to monitor the state of volcanoes and predict potential hazards. [26] builds a seismological data warehouse for earthquake prediction. Many early warning systems have been set up for tsunamis [33]. In addition, disasters often cause other kinds of disasters, becoming multi-hazards. Floods are a multi-hazard example because they can lead to landslides and spread of diseases. A single sensor stream for flood is insufficient for detecting flood levels or diseases. Multiple sensors have to be combined. In this scenario, humidity, water level, wind velocity, rainfall, landscape, and water quality data are such data sources and thus can be integrated for flood and successive hazard responses. Despite the development of both models and sensor technology, the technology to utilize all these data sources currently exists in silos. A multimedia system can help assimilate and communicate this information.

As information sources complementary to the above sensors, social media and sensors in smartphones are becoming powerful mobile sensors in disaster management. In particular, Twitter data has been used in various disasters, such as a hurricane [16], an earthquake [10], a flood [36] and a tsunami [3]. Another commonly used social media data for disaster management is Foursquare. Foursquare has a 'check-in' feature to show where the users are. By aggregating the occurrences of 'check-in', the density of population can be estimated. When Hurricane Sandy happened, comparisons of the densities of 'check-in' before, during and after disasters showed how the disaster affected the functioning of different zones in the city [13]. A simple feature in Facebook now allows people to declare that they are safe during disasters. In addition, [40] proposes a mobile data computing framework consisting of data collection, data processing, and data representation. However, this framework considers only images and documents from social media and the web. [21] develops a visual analytics system and multimedia enabled mobile application for access to relevant disaster situation information. [39] designs a multimedia-aided disaster information integration system, which utilizes data mining techniques to analyze situation reports as well as pictures and text captured in the fields, and automatically links the reports directly to relevant multimedia content. However, all these frameworks limit themselves to social media data, and thus fail to assess the disaster situation with a comprehensive understanding of the environment because they do not combine this user-generated content with other sensory information.

Integration of physical sensors and social media is starting to get attention in disaster management. [25] proposes a landslide detection system to combine physical and social information and provide services for citizens. However, there is a growing consensus that social media provides useful but insufficient data for accurate event or situation recognition.

3. CLASSIFICATION OF DISASTERS

Disasters have varying magnitude, temporal and spatial dimensions, and varying social and economic consequences. They range from predictable to unpredictable, from intense to diffuse, and from those caused by natural factors to those caused by humans. A detailed taxonomy of disasters has been developed [9] and may be useful while developing systems for dealing with specific disasters. In this section, we classify disasters based on their technology requirements and spatio-temporal nature of multimedia information processing.

We categorize disasters into two main categories and illustrate how multimedia can contribute to disaster management research in both areas. The first category includes 'sudden' natural hazards such as floods, hurricanes, and earthquakes. The second addresses a slower 'creeping' crisis [6] which builds up gradually, often over many years, and includes a climate change, global warming, land degradation and air pollution. For the three stages of disaster management, on one hand, a prompt *response* is more critical for saving lives during a sudden crisis; on the other hand, the efficient and effective collection and use of data is more important for the *planning* and *recovery* phases in a creeping crisis.

3.1 Sudden Impact Disaster

Some disasters happen suddenly and may occur for a limited time. For these disasters, planning time is short. Their impact on people is severe and needs time sensitive responses. We consider these to be sudden impact disasters which lead to an immediate emergency response situation.

The response to these disasters includes help for finding a safe place, medicine, food, and information about friends and families. Real-time and prompt decisions are crucial. For example, during floods people in affected areas panic about what action they should take: should they stay home or evacuate to a shelter? In the past, this information was usually broadcasted to the whole community, but now we can do better and provide personalized instructions to an individual or a small group of people using their smartphones. To help people, data from physical sensors (like flood level monitors), and from governmental or other sources (like available shelters) may be obtained and used. In cases where the above data sources are not available, people in the flooded area themselves can still provide accurate and rich information including texts, images, and videos for the benefits of individuals and societies.

The goal of multimedia emergency response platforms should be not only recognizing the current emergency situation like flood severity, but also providing actionable information such as the location of the nearest accessible shelter. In this case, end users could be flood victims trapped in their homes or in their cars on flooded roads, or volunteers/organizations who provide help and resources. In general, the requests are collected from citizens, and organizations may take actions, share information, and coordinate with each other through different communication channels.

3.2 Creeping Disaster: Air Pollution

The other kind of disaster is the one that builds up slowly. Initially, their effect may not be felt. It is only after some time that their effect creeps into the life of people.

The *planning* and *recovery* stages play the most crucial roles in the long-term effects of such disasters. We use air pollution as an example. Air pollution is increasingly becoming a serious world-wide problem which attracts a lot of attention from disparate sectors. This problem is difficult to solve because of various emission factors, such as meteorological phenomena, road networks, traffic flows, point of interests, land uses, power plants, and emergent events (e.g., forest fires). These data are usually stored at multi-agency databases and in different formats. Governments need powerful tools to effectively handle and process these seemingly incompatible but often highly correlated streams in order to create proper emergency plans.

On the other hand, citizens can only rely on sparse situational reports from a few media sources to accurately assess air quality information. As a result, both governments and citizens often make plans and decisions based on incomplete information. Instead of relying on noisy data from social media, the governments can benefit from specific participatory citizen reporting, which provides a straightforward and accurate way for citizens to report situations. Environmental situations and people's feelings can be reported using photos and texts. Given photos of a sky, computer vision techniques can be employed to compute the haze level [20].

Major challenges in this area are related to accurately assessing slowly evolving situations, before they become severe. Once the situation becomes a crisis, the *response* phase becomes more important, similar to the sudden impact disaster.

4. MULTIMEDIA INFORMATION IN EMERGENCY SITUATIONS

Emergency response and situation recognition have always been a subject of interest to many disciplines and have been an active area of research. Many aspects of computing technology have been used in different forms in disaster management. GISs, databases, mobile computing, and sensor networks have all play different roles in rescuing people during disasters. All these technologies, however, have been used in isolated manners and in different silos. We believe that multimedia computing can bring them together for the purpose of building a unified framework for this important aspect of our society.

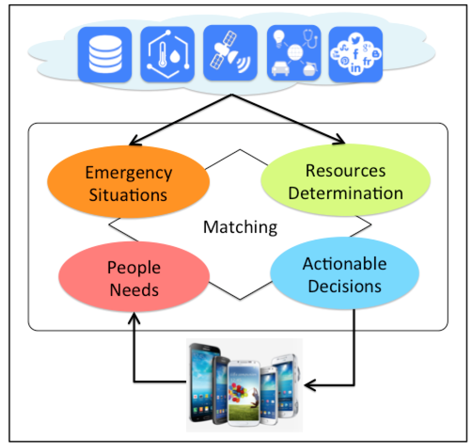


Figure 2: Multimedia systems for managing emergency situations

An obvious fact needs to be mentioned here, however. During disasters, many commonly used systems may not work due to power failures and other breakdowns in essential services. That is usually a serious problem. A multimedia technology used through smartphones is a safer option than physically connected components. But, if even wireless networks are not working, then we are back to the worst situation without help from any technology.

Norbert Wiener introduced the concept of cybernetics in 1948 [38]. Recent progress in sensors, IoTs, social networks, actuators, and information systems makes his ideas very relevant in today's societal systems. Given today's sensors, mobile framework, processing power, and participatory sensing, real time emergency response systems can now be designed using cybernetics.

Cybernetic principles - building models, measuring parameters, estimating states, and controlling the system - may play a key role in addressing problems at a societal level in many complex applications. We have diverse sensors that are inexpensive and already being used to collect observation streams at diverse locations. This motivated us [17] to explore solutions for critical problems in societal systems.

Situation recognition is crucial for closing the loop by sending an actuation or actionable information to match appropriate needs and resources. A basic architecture for an emergency response system is shown in Figure 2. These systems have the following major components: emergency situation recognition, determining resource locations, personal needs determination, and taking action to match needs and resources. For designing emergency response systems, we must use all available sensors, and all data and information sources.

In the following, we first discuss challenging research issues and then present some approaches to address them, including a prototype system. We must mention that what we present is an early prototype. The field of emergency situation recognition and appropriate response using multimedia information needs serious research in all the issues, and possibly many more, mentioned in the following section.

5. RESEARCH CHALLENGES

In this section, we address ten essential research challenges in building multimedia systems to manage emergency situations. Our goal is to inspire and provide high-level guidance to researchers in a multimedia community. We also aim to build a multimedia emergency response community. Each of these challenges is really a well defined research area that will evolve as the requirements are better identified in the process of building complete emergency response systems. These multimedia research problems could be addressed by researchers as independent research problems. Of course, some researchers may build complete systems by combining several of these.

1 **Data Identification:** In dealing with emergency response, the first question that one faces is: *how to gather all related data to evaluate and assess this emergency situation?* In the last few years, access to public data from both governmental sources, such as NASA, as well as non-governmental sources, such as Google, has become much easier. Many emerging applications and social media systems also make their data publicly available through APIs. As shown in Section (6), it is possible to build a very useful application by using data streams available on the Web from popular sources. Of course, it will be very useful to provide an environment to discover relevant data sources of different media types and to do research for assessing the quality of data sources so that appropriate sources can be selected at relevant locations. The research challenge is to define a measure for the quality of data sources in the context of specific types of emergencies.

2 **Data Processing:** Increasingly, data is heterogeneous streams. Data is collected by sensors with geo-spatial attributes and meta-data. People with their smartphones are smart sensors. The values obtained directly from sensors may range from measured facts(i.e. traffic flow) to reporting by people. The challenge is to deal with these values taken from disparate sensors and reconstruct the state by mapping sensors to attributes that are relevant in the context of computing the particular situation. A system needs to deal with the synthesis of spatio-temporal data collected at different spatial scales and temporal frequencies. For decades, GISs combine spatial data of different resolutions. However, grid resolution is usually selected without any application-specific justification. Creation of methodological guides to select a suitable grid resolution when designing a model to combine heterogeneous spatial data sets for a specific application is a new research problem. At this resolution, the model should assure that the uncertainty in the results is acceptable and the processing cost is minimal or reasonable.

3 **Multimedia Participatory Sensing:** Participatory sensing utilizes the eyes and ears of citizens to collect information about a situation. Twitter introduced micro-blogging that has been widely used as participatory sensing. However, Twitter is too broad and subjective for most emergency applications [4]. Crowdsourcing on disaster assistance has been widely studied and considered useful for tracking the latest status of emergency situations [11, 12]. For the changing demographics of the society and now significantly more powerful smartphones, it is possible to create more powerful multimedia participatory sensing approaches using multiple sensors and other contextual information. A very interesting and potentially transformative research challenge is to use computer vision and contextual reasoning to capture powerful micro-reports that will rapidly identify people's need in given situations and help them get to resources. Participant sensing is valuable, but it also raises privacy issues. Some information related to a reporter's context may reveal information that she may not normally want to divulge, for example a report from a gay bar may reveal sexual orientation. Due to the time sensitivity of reports, traditional ways of preserving privacy are unlikely to work. Solving privacy related issues for emergency situations are open and challenging problems.

4 **Heterogeneous Data Quality:** In the real world, sensors are spatially sparse, preferentially located and often lack complete measurements in targeted temporal resolution. Reliance on these measurements not only restricts the geographical region of situation recognition, but can also result in temporal uncertainty. There is a great need for spatial and temporal interpolation to increase the availability of these data across space and time. One of the challenges is to combine data sources that are at different resolutions. For example, one data stream is provided as grid cells, while other data streams are only available at point locations. One data stream is available in hours, while the other data stream is in days. Complex missing data and misalignment problems offer another research challenge. The research challenge here is to develop approaches to allow the effective associations between data at different spatial and temporal resolutions and to use them to create dense representations as needed.

5 **Situation Recognition based on Historical Data:** Cameras and sensors are deployed at different locations to continuously monitor target conditions, for example, traffic flow, air pollution, and temperature. When such data streams are combined to provide actionable information, discovering the spatially correlated and frequently evolving patterns is challenging: First, informative patterns are often flooded by trivial fluctuations. Second, the pattern search space is extremely large. A pattern can contain an arbitrary number of sensors, and the matching time intervals are at different scales. This results in an exponential pattern search space, calling for novel and efficient pattern search methods. This data may offer a novel challenge for current machine learning techniques. Situation recognition may very well be the next major research challenge for machine learning after recent great progress in concept recognition in images.

6 **Real-time Situation Recognition:** During disasters, response time is critical. The computation or processing time of large volumes of data can take too much time to be useful. For example, reporting about flooding risk every hour during a normal day is acceptable, but during the heavy raining seasons the hourly

reports of flooding risk areas may not be sufficient. A real-time visualization can serve as a first step to build a real-time situation recognition engine. The engine must have the capability to do real time visual analytics for evolving disaster situations. Communication disruption is an important factor in recognizing the severity of a sudden crisis. Total disruption suggests an extreme situation. In case of a partial disruption, the system needs to adjust for sampling bias of the severity of the situation, using prior knowledge such as population density, as well as estimate of the severity from prior situations. The research challenges here are to develop new architectures for real time processing of massive volumes of heterogeneous streaming data.

7 **Predictive Analytics:** Recognition of situations in real-time is good, but it is much better if the disaster situations are predictable. One example is the use of multimodal data and multimedia modeling tools to predict an area that might face future flooding [2]. An accurate prediction of the severity and disastrous flooding will significantly reduce the damages. The major problem making prediction difficult is the complexity of disaster behaviors . One interesting approach is to use high resolution 3D technologies to simulate and visualize realistic catastrophe behavior. Spatio-temporal dimensions also have to be considered in the predictive analytics.

8 **Communication Technology:** Rapid deployment of personalized communication systems during emergencies is a primary challenge. When disaster strikes, whole geographic regions may suffer loss of power, a high volume of telephone calls, and disruption in road services and other infrastructure. By relying on multiple information communication approaches, one may increase robustness during difficult times. Moreover, generally power based land connections usually fail first; wireless connectivity based on batteries is more reliable. Thus information collection and communication based on smartphones is likely to be more reliable than traditional infrastructure. In the case of severe disruptions in communication infrastructure, peer-to-peer networks may be useful for exchanging information. [22] presented a reliable ad-hoc network, called CalMesh, to restore the communication fabric at the site of the crisis. Even in the case of total infrastructure failure, multimedia data collected by people will still be the most powerful mechanism for documenting the situation. Once these data are available for analysis following the crisis, we will be able to understand the situation better for future planning.

In addition to physical mediums, trust and focus also play a very important role. How could one determine whether information may be trusted? How could one send information only to relevant people rather than sending everything to everybody, which results in an overload of information and which is associated with the tendency to consider it irrelevant. The challenge is to develop technology that can be quickly deployed to create 'altruistic communities' in which people can trust and assist fellow community members and the right information can be sent to the right person at the right time.

9 **What-If-Scenario Analysis:** Decision makers may not have a clear idea of what is the best action in an emergency situation. It is common to experiment and deploy strategies. In many complex situations, decision makers are provided tools for what-if analysis. These tools include doing rapid simulations to evaluate which strategy may work better. Since each emergency situation may be unique, it is important to do simulations using the situation under consideration. As far as we know, this problem remains unaddressed because until recently neither sufficient data nor computational tools were available. Now all these are available and hence this may be a research challenge that may become a very valuable decision analysis and support tool.

10 **Decision Support and Recommendation System:** In order to connect needs and resources, as well as optimize the need matching, the first challenge is to recognize where the citizens actually are and what they are doing. During disasters, citizens might be guided by disparate and perhaps inconsistent information sources and different decision making models. Thus, the locations and behaviors might be continuously changing. Tracking the locations and behaviors of citizens are important for allocating resources to aid them. Using multimedia data like photos, audio, and signals from wearable devices to detect activity and emotion [15] can be critical for personalized responses. The research challenge here is to develop multimodal recommendation engines that are not only multi-dimensional but also sensitive to time and location.

6. MANAGING EMERGENCY SITUATIONS: A PRELIMINARY SYSTEM

We present our ideas and demonstrate our early attempts to deal with the issues discussed above. The system described below is meant to demonstrate the feasibility and potential of a multimedia system for managing emergency situations. This multimedia system is a more holistic approach for disaster managements. Our idea consists of four main components. The first three components are developed and made available as open-source tools for researchers to use. We expect to continuously improve these early versions with the help of the multimedia research community. The last component is an ongoing project.

6.1 EventShop

The fundamental nature of data streams observing real-world events measured by either physical or human initiated sensors is almost always associated with time and geospatial meta-data. This commonality between different streams motivated us to develop an open-source EventShop system [32] to solve some problems in Research Challenges (**1**), (**2**), (**4**) and (**6**).

There are several approaches to modeling spatio-temporal and thematic data [27, 31, 37]. A spatial grid structure is natural for representing various geospatial data, where each cell of the grid stores a value of observations and attributes at the corresponding geo-location, at a given time. Other structures can be superimposed on this and corresponding attributes could be derived. We adopted the grid

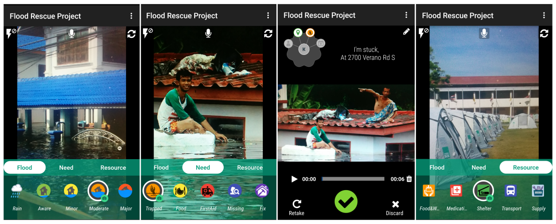


Figure 3: Flood multimedia micro-reports using Krumbs intents

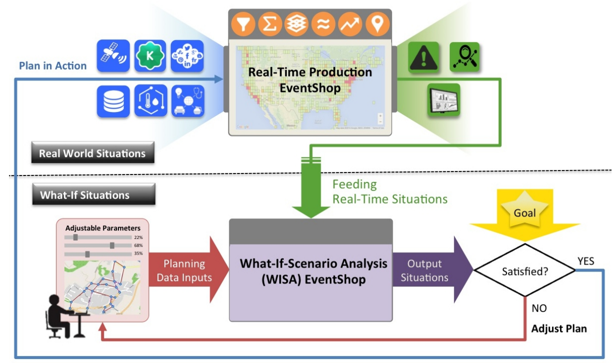


Figure 4: WISA architecture using EventShop for city plan decision making

structure in EventShop, and called it an Emage [29]. Techniques like [5] enable efficient processing of multiple streams. This generic data model can be used to efficiently and effectively integrate heterogeneous data coming from spatio-temporally distributed disparate data streams. Several applications have used the EventShop framework to recognize real world situations. For example, hurricane and flood detection, disaster mitigation, demand hot-spots of business products identification, flu outbreaks, wildfire detection, and allergy risk estimation and patient recommendations [28, 34].

In its current form, EventShop has:

- A data ingestor to obtain data from disparate sources, and transform it to the Emage format.
- A set of operators to select, segment, aggregate, characterize, spatially and temporally filter, and cluster spatio-temporal data streams.
- A query processing engine to process 'standing queries'[28] created using stream processing operators.
- Map visualizations of input and output streams.
- A rule based action engine that can execute tasks depending on detected situations.

Overall, EventShop accepts diverse data streams, provides appropriate mappings to obtain relevant attributes, converts this data to information events, and then assimilates these event streams into evolving situations.

6.2 Multimedia Micro-reports

In today's data-rich environment, a lot of data is readily available from many public sources, proprietary sources, IoTs, and databases. Increasingly, participatory citizen sensing and crowdsourcing are playing more important roles in understanding current trends and evolving situations. Non-people sources are combined with people sources by weighting them according to the situational context.

Citizen contributed data comes in the form of streams from mobile devices carried by people. In EventShop, persistent location sensor data, air pollution data, and pollen data were combined with citizen-contributed Twitter data to study an asthma risk situation. The accuracy of situation detection depends on the quality of data. However, micro-blogs from systems like Twitter are very noisy and subjective [4, 7]. Most applications may benefit from objective and factual citizen contributed data. Waze is a mobile app that uses GPS data from its users as micro-reports to estimate the real-time road traffic, and provides an actionable guidance such as the best route.

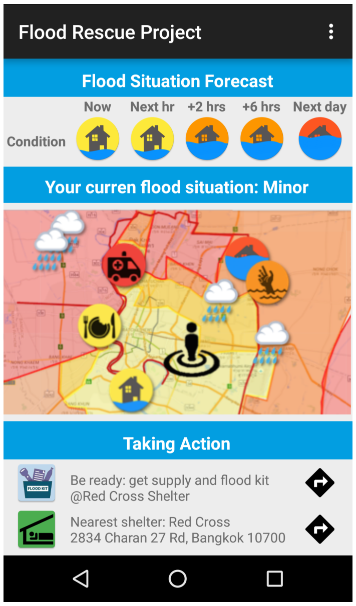
We are exploring **multimedia micro-reports** [29], compared to **micro-blogs**, for radical improvement in the quality of participatory sensing data as in (**3**) and (**8**). Initially, we are using Krumbs from a young company championing micro-reports; later we will extend our approach to include other sources also in this paradigm. Krumbs is a platform for reporting specific situations. Krumbs uses an **Intent Camera** that combines contextual reasoning with the intent of the reporter. This camera also allows people to express opinions and contribute other information. Krumbs maintains the distinction between objective (from sensors), derived (using computational approaches and reasoning), and subjective information (from a user's opinion). A report is represented in media-JSON format. The use of media-JSON allows linking, search, and analysis using different existing platforms. An example of multimedia micro-report for a flood situation using Krumbs SDK is shown in Figure 3. We classify types of multimedia micro-reports into three categories:

- **reporting current flood situation**: heavy rain, low/ medium/ high water level, submerged vehicles, flood risk, crime report.
- **requesting needs**: medical needs, trapped in the house, trapped in the car, missing person, missing animal, needs food and water, needs sandbag.
- **offering aid and resources**: opening shelter, availability of existing shelter, safe parking spots, serving meals, distributing supplies.

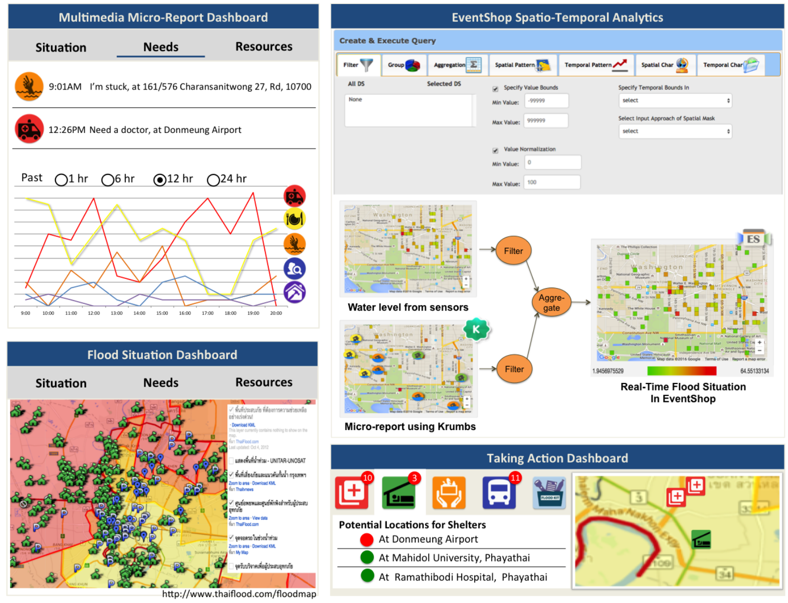
6.3 Situation Recognition and Prediction

Situation recognition based on the latest observations alone could be too late for taking appropriate actions for critical events. Accurate predictions of situations can allow adequate time to take appropriate actions by connecting people to the resources they need, especially in life threatening situations. Typically, predictions in specific fields are derived from numerical models and data. By utilizing large scale data integration, machine learning models can be used in conjunction with scientific theory based models to obtain more accurate predictions and contribute to solving problems in Research Challenges (**5**) and (**7**).

Common methods for a time series prediction are auto-regressive, moving average, and auto-regressive moving average models [14]. Multivariate spatio-temporal auto-regressive



(a) Managing flood situation mobile app



(b) Flood Situation Dashboard

Figure 5: Dashboard for citizens and city planners

models take into account both spatial and temporal correlations but require an estimation of a large number of parameters. In order to reduce the number of estimated parameters, models can be developed which consider the spatial and temporal correlation in neighbors similar to [24]. Models can also be designed to incorporate spatio-temporal correlation by using tensor time series [30]. Those models can manifest hidden and evolving trends in the multidimensional data by preserving the sensor structure. Deep neural networks have become the state of the art in audio and vision, and have extended their applications to more fields. We aim to implement machine learning models in EventShop with a built-in ability to cope with STT (Space-Time-Theme) data.

6.4 What-If Scenarios Analysis

In many complex planning tasks, a planner uses his situational awareness to perform What-If-Scenario Analysis (WISA) to anticipate changes for deciding the action plan. The goal of WISA is to consider the current situation and simulate possible actions to project the results. By considering many alternative action scenarios, a decision for the optimal actions for deployment emerges. A very simple example of WISA is the use of spreadsheets to decide optimal actions. In the case of complex systems like the disaster management, this action planning needs powerful scenario analysis tools. As far as we know, this has not been tried thus far in disaster management planning using big data sets (**9**) and (**10**).

To implement such an approach, one needs to run two versions of EventShop in parallel. One version is the production version and the other is for experimenting. At any given instant the experimental version can copy the situation outputs from the production version. The experimental version can then apply proposed inputs to see their effect on the system by running the system starting with the current state and using simulated inputs and prediction operators at a faster speed. This will help in understanding how the situation evolves if particular decisions were implemented.

Figure 4 presents this architecture. The top part is the operational EventShop where real-time input data from various sources are used for situational awareness. The current state is continuously fed into the WISA EventShop as shown in the bottom of the figure. The city planners working with the WISA EventShop explore What-If scenarios by varying their planning data inputs. The WISA EventShop will combine both the real-time situation and planning input to generate a ‘to be’ situation. If this situation satisfies their goal, the plan will be executed, otherwise new configurations will be explored.

In summary, the multimedia systems for disaster management must deal with some new requirements. Our proposed framework is related to some of challenges discussed and accomplishes some essential functionality; specifically, it:

1. Enables effective and efficient citizen reporting and combines that with other data streams.

2. Predicts evolving situations by combining current situations with historical data as well as data related to prior planned actions. This step is essential for disaster management implementations.

3. Use of What-If scenarios for enabling decisions by planners and decision makers. This will provide a platform to help in enabling time-sensitive data based decisions using different planning and action scenarios.

7. PROOF OF CONCEPT: REAL SCENARIO

We demonstrated, and successfully used, EventShop and related systems during several disasters [28].

Managing Flood: Yesterday and Tomorrow

When the second co-author joined University of California, Irvine in 2011, there was a catastrophic event in her home country. Several major cities, including the capital city of Thailand, were flooded. During flood situations, it is very important to understand and enhance the ways in which the dynamic aspects of emergency affects citizens. Organizations should make quick plans for evacuations and provide shelters. She decided to use her knowledge and the EventShop system to manage this emergency situation. Within a day, she and her lab-mates began to collect data, recognize flood situations, and provide actionable information to citizens who were in affected areas [28].

To build this flood management application using EventShop, they first searched for any public data sources related to the Thai flood from both professional and social media sources. The former sources included flood affected areas across Thailand[2], Bangkok risk areas and water barriers, shelters' locations and availability[3], parking areas, satellite images, and flood extents. On the other hand, citizens reported their concern via text messaging and uploaded photos or video through a variety of social media sources. Since the multimedia micro-reports component was not yet available at that time, tweets associated to specific hashtags such as "#น้ำท่วม", "#ThaiFlood", and "#Flood" across the center part of Thailand were continuously harvested.

After identifying available data sources, several situation models were created to detect and recognize flood situations. The flood areas were classified into three categories based on flood conditions and shelter sufficiency. Then, for those people who tweeted about flood from the dangerous zones, the EventShop system automatically sent tweets to them and directed them to the nearest shelter in the safe areas. Some of the tweets were being re-tweeted by tweet receivers showing that they received and possibly found them useful.

This project was conducted five years ago. Several components were limited and the multimedia micro-reports did not exist. Now, advanced technologies may bring many new opportunities such as visual concepts detection using deep learning technologies in micro-reports for much better situation assessment and communication. The following is our vision for building the next generation multimedia system for managing flood situations. We design and implement a mobile app that allows users to report current flood situations, request help, and provide information about resources' availability as shown in Figure 3. The users can effortlessly submit their reports using predefined categories. Figure 5(a) shows the mobile dashboard with up-to-date information such as a flood situation forecast, a current situation around a user, and a personalized actionable recommendation. This dashboard acts as the first line of communication between citizens and authorized organizations. To forecast the flood situation, the water level flood model is created based on the historical flood events. We use data from water sensors, precipitation, and satellite images to create the flood model. Then, we used real-time flood levels detected by EventShop to adjust the model and improve the accuracy of the flood prediction model as show in Figure 6.

The first goal is to identify affected areas where people need help the most. Furthermore, we can use this information to find optimal shelter locations during evolving flood situations. We propose a city planners' dashboard in Figure 5(b). The multimedia micro-reports from our mobile app are located on the top left with three tabs that corresponding to the three categories of reports. All reports are shown in the list and line chart over time. In the bottom left, data from authorized resources are represented in the map view. On the top right, EventShop provides an experimental environment where analysts can plug in different types of operators onto any data sources to create a complex situation recognition model. For example, water physical sensors and flood situations from multimedia micro-reports are aggregated to create a finer and more complete water situation. The bottom right is where need-resource matching takes place.

[2]www.thaiflood.com/floodmap

[3]www.shelters.thaiflood.com

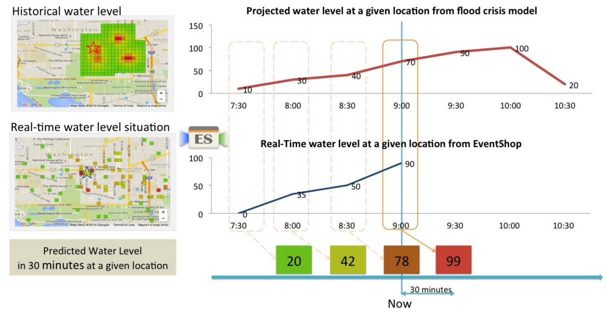


Figure 6: Predicted flood level

8. CONCLUSION

Effective disaster management can potentially save lots of lives and resources. However, to build such a system, currently many technologies such as GIS, sensor networks and mobile computing are used in different silos. We believe that multimedia computing can bring them together to create a unified framework for managing complex emergency situations. Ten major research challenges in building multimedia systems for managing emergency situations are addressed and discussed. We also present one example approach that has been implemented in our laboratory using EventShop and multimedia micro-reports. Given enormous progress in concept and activity recognition using machine learning in the past few years, we foresee a great opportunity for emergency situation recognition using multimedia technologies. The time is right and ripe for the multimedia community to address challenges in managing this important societal problem.

9. REFERENCES

[1] 2011 thailand floods. https://en.wikipedia.org/wiki/2011_Thailand_floods.

[2] Modelling better flood responses in port phillip bay. http://www.csiro.au/en/Research/D61/Areas/Data-for-decisions/Disaster-management/Flood-modelling. Accessed: 2016-07-23.

[3] A. Acar and Y. Muraki. Twitter for crisis communication: lessons learned from japan's tsunami disaster. *International Journal of Web Based Communities*, 7(3):392–402, 2011.

[4] L. Barbosa and J. Feng. Robust sentiment detection on twitter from biased and noisy data. In *ICCL*. Association for Computational Linguistics, 2010.

[5] D. Carney, U. ÃĞetintemel, M. Cherniack, C. Convey, S. Lee, G. Seidman, M. Stonebraker, N. Tatbul, and S. Zdonik. Monitoring streams: a new class of data management applications. VLDB 2002.

[6] S. De Paratesi and E. Barrett. Hazards and disasters: concepts and challenges. *Remote sensing for hazard monitoring and disaster assessment: marine and coastal applications in the Mediterranean region*, pages 1–17, 1989.

[7] L. Derczynski, A. Ritter, S. Clark, and K. Bontcheva. Twitter part-of-speech tagging for all: Overcoming sparse and noisy data. In *RANLP*, 2013.

[8] R. Di Salvo, P. Montalto, G. Nunnari, M. Neri, and G. Puglisi. Multivariate time series clustering on geophysical data recorded at mt. etna from 1996 to 2003. *Journal of Volcanology and Geothermal Research*, 251:65–74, 2013.

[9] T. E. Drabek. *Human system responses to disaster: An inventory of sociological findings*. Springer Science & Business Media, 2012.

[10] P. S. Earle, D. C. Bowden, and M. Guy. Twitter earthquake detection: earthquake monitoring in a social world. *Annals of Geophysics*, 54(6), 2012.

[11] H. Gao, G. Barbier, R. Goolsby, and D. Zeng. Harnessing the crowdsourcing power of social media for disaster relief. Technical report, DTIC, 2011.

[12] M. F. Goodchild and J. A. Glennon. Crowdsourcing geographic information for disaster response: a research frontier. *International Journal of Digital Earth*, 3(3):231–241, 2010.

[13] N. Grinberg, M. Naaman, B. Shaw, and G. Lotan. Extracting diurnal patterns of real world activity from social media. In *ICWSM*, 2013.

[14] J. D. Hamilton. *Time series analysis*, volume 2. Princeton university press Princeton, 1994.

[15] R. Hegde, B. Manoj, B. Rao, and R. Rao. Emotion detection from speech signals and its applications in supporting enhanced qos in emergency response. In *Proceedings of the 3rd International ISCRAM Conference*, 2006.

[16] A. L. Hughes and L. Palen. Twitter adoption and use in mass convergence and emergency events. *International Journal of Emergency Management*, 6(3-4):248–260, 2009.

[17] R. Jain and D. Sonnen. Social life networks. *IT Professional Magazine*, 13(5):8, 2011.

[18] S. Jain, R. C. Shah, W. Brunette, G. Borriello, and S. Roy. Exploiting mobility for energy efficient data collection in wireless sensor networks. *Mobile Networks and Applications*, 11(3):327–339, 2006.

[19] G.-H. Kim, S. Trimi, and J.-H. Chung. Big-data applications in the government sector. *Communications of the ACM*, 57(3):78–85, 2014.

[20] Y. Li, J. Huang, and J. Luo. Using user generated online photos to estimate and monitor air pollution in major cities. In *ICMCS*, page 79. ACM, 2015.

[21] S. Luis, F. C. Fleites, Y. Yang, H.-Y. Ha, and S.-C. Chen. A visual analytics multimedia mobile system for emergency response. In *IEEE International Symposium on Multimedia*. IEEE, 2011.

[22] B. Manoj and A. H. Baker. Communication challenges in emergency response. *Commun. ACM*, 50(3):51–53, Mar. 2007.

[23] B. Merz, H. Kreibich, and U. Lall. Multi-variate flood damage assessment: a tree-based data-mining approach. *Natural Hazards and Earth System Sciences*, 13(1):53–64, 2013.

[24] W. Min and L. Wynter. Real-time road traffic prediction with spatio-temporal correlations. *Transportation Research Part C: Emerging Technologies*, 19(4):606–616, Aug. 2011.

[25] A. Musaev, D. Wang, and C. Pu. Multi-hazard detection by integrating social media and physical sensors. In *Social Media for Government Services*, pages 395–409. Springer, 2015.

[26] S. L. Nimmagadda and H. Dreher. Ontology based data warehouse modeling and mining of earthquake data: prediction analysis along eurasian-australian continental plates. In *IEEE ICII*, 2007.

[27] M. S. Perry. *A framework to support spatial, temporal and thematic analytics over semantic web data*. PhD thesis, Wright State University, 2008.

[28] S. Pongpaichet, V. K. Singh, M. Gao, and R. Jain. EventShop: Recognizing Situations in Web Data Streams. In *WWW*, 2013.

[29] S. Pongpaichet, M. Tang, L. Jalali, and R. Jain. Using photos as micro-reports of events. In *ICMR*, 2016.

[30] M. Rogers, L. Li, and S. J. Russell. Multilinear Dynamical Systems for Tensor Time Series. In *NIPS 2013*.

[31] A. Sheth and M. Perry. Traveling the Semantic Web through Space, Time, and Theme. *IEEE Internet Computing*, 12(2):81–86, Mar. 2008.

[32] V. K. Singh and R. Jain. *Situation Recognition using EventShop*. Springer; Auflage: 1st ed. 2016, 2016.

[33] J. H. Sorensen. Hazard warning systems: Review of 20 years of progress. *Natural Hazards Review*, 1(2):119–125, 2000.

[34] M. Tang, P. Agrawal, S. Pongpaichet, and R. Jain. Geospatial interpolation analytics for data streams in eventshop. In *ICME*. IEEE, 2015.

[35] M. S. Tehrany, B. Pradhan, and M. N. Jebur. Spatial prediction of flood susceptible areas using rule based decision tree (dt) and a novel ensemble bivariate and multivariate statistical models in gis. *Journal of Hydrology*, 504:69–79, 2013.

[36] S. Vieweg, A. L. Hughes, K. Starbird, and L. Palen. Microblogging during two natural hazards events: what twitter may contribute to situational awareness. In *CHI*, pages 1079–1088. ACM, 2010.

[37] X. Wang, X. Zhou, and S. Lu. Spatiotemporal data modelling and management: a survey. In *ICTOOLS*. IEEE, 2000.

[38] N. Wiener et al. *Cybernetics*. JSTOR, 1948.

[39] Y. Yang and S.-C. Chen. Multimedia big mobile data analytics for emergency management. *E-LETTER*, 2015.

[40] Y. Yang, W. Lu, J. Domack, T. Li, S.-C. Chen, S. Luis, and J. K. Navlakha. Madis: A multimedia-aided disaster information integration system for emergency management. In *CollaborateCom*. IEEE, 2012.