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CROWD-BASED PROCESSING OF SOCIAL MULTIMEDIA TO SUPPORT INFORMATION ASSESSMENTS IN DISASTER RESPONSE

[1] H. FRITZE, [2] E. CLEMENTINI, [2] S. BREDA, [1] C. KRAY

[1] Institute for Geoinformatics, University of Muenster, Heisenbergstraße 2, 48149 Münster, Germany

[2] Industrial and Information Engineering and Economics, University of L'Aquila,

Via Giovanni Gronchi 18, 67100 L'Aquila, Italy

E-mail: [1] {h.fritze | c.kray}@uni-muenster.de, [2] eliseo.clementini@univaq.it

ABSTRACT

At the onset of a disaster, the rapid assessment of relevant information is one of the most critical challenges for decision-makers at all levels. The proliferation of social networking software combined with the increasing pervasiveness of smartphones has established new sources of very timely and current information. However, crowd-sourced social media suffer some major drawbacks hindering its efficient use. Aid organizations and agencies need to be able to rely on a valid and relevant set of information, which they can incorporate systematically in their response actions. This paper addresses the identification of potentially relevant photos shared through social networks and their preparation for a rapid spatial assessment. We present a conceptual framework for a crowd-based, semi-automated approach of processing photos to leverage them for a spatial information assessment. The framework enables ad-hoc volunteers to digitally support response actions by reviewing, georeferencing, and annotating shared photos. We introduce a prototype called DisasterMapper, which retrieves photos from Twitter and provides a geovisualization tool for semi-automatic human processing and annotation. In two different evaluations, we were able to demonstrate that digital volunteers can successfully process social multimedia content and create a set of valuable photos applicable for systematic information assessment operations.

Keywords: *Social Multimedia, Micro-Tasking, Interactive Geovisualizations, Digital Volunteers, Crowd Processing*

1. INTRODUCTION

The EM-DAT database for emergency events[1] reports a rising number of natural disasters and an increasing total economic loss, turning major incidents into a more severe threat to our societies. Therefore, the efficiency of managing disasters and reducing the direct effects of an impact has gained increasing attention. The response phase is characterized by rapidly changing situations and the need for timely and targeted actions to lower the direct and indirect effects of the disaster. A disaster often results in unpredictable and dynamic changes of a given situation, making the response phase particularly challenging [1]. This phase aims to provide immediate assistance to save lives, improve health and support the morale of the affected population [2]. It includes activities, such as warning and evacuation, search and rescue, providing immediate assistance, assessing damages, and the immediate restoration of the infrastructure.

Before deploying response actions, decision-makers must obtain a profound understanding of the situation at hand, e.g., the severity of the disaster, the number of people affected, and the urgency of demands. The acquisition, assessment, processing, and communication of information are some of the most crucial aspects of this phase. Amongst several different ways to gather information, the affected population is a valuable source for first-hand information, and the integration of this information is highly valuable to cover the information gap occurring at the disaster onset [3]. In the past, the population's primary contact point for disaster officials was calling the

[1]http://emdat.be/emdat_db (visited 09.08.2018)

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emergency hotline. However, the way people communicate during a disaster has changed. The popularity and accessibility of social media and social networking services and the development of smartphones have established new data sources and infrastructures. Scholar demonstrated the critical role social media can play in natural disasters as an information propagator [4]–[6]. Leveraging this source can provide emergency responders with more specific and timely information than official data from aid agencies or governmental organizations can do.

The Haiti earthquake is often pointed at as the watershed moment that changed how social media is used during disasters. In fact, following the earthquake in January 2010, numerous messages and photos were shared via social media sites, such as Twitter, Flickr, Facebook, and blogs [7], [8]. Over two million tweets were posted following the earthquake [9]. Similar observations have been made in subsequent events, such as the 2012 Hurricane Sandy in the USA [10], the 2013 Typhoon Haiyan in the Philippines [11], or the 2015 Chennai Floods in South India [5]. The consideration of Social Media as new data sources has several advantages. First, during disasters, conventional cellular and landline communications often experience a partial or total outage due to bandwidth requirements, while internet-based networking services stay active. Second, emergency hotlines are often overwhelmed with the amount of incoming calls [12]. Third, smartphone applications can provide the exact geolocation of the user, which can be very helpful. Geo-tagged messages, images, and videos (e.g., Twitter) allow relief organizations to accurately locate specific information. In contrast to pure text messages, photos and videos are likely to provide factual and more objective information. An existing georeference can further increase the information value. In addition, visualizing those multimedia items on a map offers a shared and integrated view on the situation at hand and helps organizations immediately to ascertain the current status.

Although social media can provide timely information about a disaster, they still fall short in supporting disaster relief efforts effectively. They provide the communicational support, but lack capabilities for structured information assessment and coordination of actions [12]. Moreover, integrating information from multiple disparate sources is a central problem. Therefore, the question arises: "How can multimedia data from various sources (e.g., phone, e-mail, social media and news) be leveraged effectively and in a timely manner for disaster relief?"

Besides technical and organizational challenges, issues of lower reliability, accuracy, and incompleteness of retrieved information prevent the integration of multimedia data into decision-making [4], [7], [13]. Data from crowdsourcing applications does not always provide all information required for disaster relief efforts [4], [7]. Messages are often duplicated, and the contained information lacks guarantees regarding its content, truthfulness, completeness, aggregation, and prioritization as well as its accuracy of georeferencing. Thus, since speed, accuracy, and completeness of information can help to save lives [14], the timely validation and verification of this information are crucial aspects [15]. At the same time, verification of individual reports is an added burden on relief organizations.

Those issues may explain why relief organizations are often reluctant to leverage crowd-sourced information. They are missing capacity to identify and assess relevant information in a timely and accurate manner. Moreover, if the information is not prioritized, organizations have difficulty to concentrate on the issues and events that are most important to the relief effort. Hence, the integration and incorporation of information from multiple sources require improvements. %Enriching official information with other, non-official information can lead to more effective crisis management systems and improve coordination.

This paper aims to leverage social multimedia for disaster response information assessments. We propose a conceptual framework that involves digital volunteers in the processing of collected photos and videos from social media outlets. The volunteers review, prioritize, georeference, and annotate potentially relevant social multimedia items to incorporate them in a well-structured way during information assessment actions. The primary focus of this research is on manual actions of the users instead of fully automated processes. The aim is to utilize the human intelligence within an often massively changed environment.

The remainder of this paper is organized as follows. In chapter 2, we review existing research and present some applications used in this context. Chapter 3 details our conceptual framework. The main aspects of the design and the implementation of the prototype are described in chapter 4, while the results of the evaluation are discussed in chapter 5. Finally, chapter 6 addresses the main conclusions and chapter 7 concludes with paper with the recommendations for further studies and improvements to the developed framework.

2. RELATED WORK

This work is located within and between different research domains and direction, i.e., disaster management, volunteer integration, as well as information retrieval, processing, and assessments of social media. This section will give an overview of scientific work from each of these fields and will locate our work within this context.

The involvement of citizens has been proven to be a useful addition to many professional domains, such as environmental monitoring or spatial planning [16]–[19]. In the domain of emergency management, research on citizen involvement and the use of social media ranges from assessments of the utility of social media [7], [20] to case studies of media use in disasters [21], [22]. A significant portion of these studies has focused on the use of online media for situation awareness in crisis situations and on tools to facilitate emergency managers' utilization of "social sensors" for situation awareness [9], [23], [24].

Research examining the social and technological aspects of emergency and crisis response refers to the domain of crisis informatics [25]–[27]. Scholars document an increasing reliance on communications networks enabled by social media during disaster events. However, current crowdsourcing applications still fall short of effectively supporting official disaster relief efforts [4]. Some reasons are given by non-existing common mechanisms for collaboration and coordination between the varieties of disparate relief organizations [28]. For example, crisis maps usually do not provide a mechanism for allocating response resources and multiple organizations might respond to an individual request at the same time. Additionally, the crowd-sourced information may be fictitious or wrong leading to limited usefulness of the information and may even influence or change the general public's attitude towards certain opinions [29]. Verifying crowdsourced information has been explored in the field of journalism [30]–[32] and emergency response [15], [33], [34]. However, crowd-sourcing applications have been considered potentially useful in many situations, although they do not always provide the complete information spectrum as needed for planning relief efforts. The accuracy of the content and its spatial reference cannot be guaranteed although greatly needed. The information is often duplicated due to forwarding and sharing. Finally, it is often not readily available or easily accessible[35].

Among a variety of social media platforms and applications, Twitter has gained major popularity and became subject to extensive scientific research [5], [36]–[39]. In contrast to other platforms with restricted access due to privacy or group setting, Twitter provides public access to its 'tweets' in a very structured way through the Twitter API. Many tweets are geotagged with a spatial reference, although this feature is by default deactivated for privacy reasons. The penetration of the service widely varies across countries. However, although its spatial distribution closely correlates with gross domestic product, the Twitter usage is not limited to particular countries or languages but is independent of such factors [40]. For these reasons, Twitter became a valuable source for voluntary geographic information (VGI) and social multimedia in particular.

The usage of social media during disasters depends on the disaster type. If many people are affected, platforms, e.g., Twitter, are primarily used for information broadcasting and brokerage [36], [41]. Following the Sichuan earthquake in 2008, messages with situational information were the most frequent contributions, especially those gathering and integrating information from multiple sources [21]. Information sharing through social media has been observed to foster a "collective intelligence"' [22]. In such emerging communities, a few individuals tend to act as active "information hubs"'. They serve as information brokers and become sources of information cascades [27], [42]. Active users with frequent contributions can serve as trusted sources of information. The inclusion of information from informal sources and the integration of ad-hoc volunteers disrupts the traditional top-down structure of emergency management and reflects a culture shift away from an authoritative control of information [43].

Another research direction focuses on analyzing the role of crisis mapping [44], [45]. Mapping tools and collaborative social media resources can rapidly provide information about important facilities (e.g., hospital locations) if such information is not known in advance. Together with newly set up locations (e.g., refugee camps or distribution camps), this information can facilitate the coordination of resource distribution [46]. Also, digital maps help volunteers to know what roads are inaccessible or the best ways to reach areas of need.

The validity of the crowd-sourced information is a significant issue for the use of social media in emergency events. Different strategies exist to verify information during emergencies [47]. Amongst those, human computing gains increasing importance within the humanitarian community. One implementation of this strategy is the Verily platform. It asks users for a fact that corroborates or discredits information posted on social media [15]. Such tool can help to sort out conflicting reports of disaster damages, which often emerge during and after a major accident. McCreadie et. al. have shown that a crowd-based approach to label rumors in social media is feasible, but tweets with controversial information still need further inspection [29]. Automated approaches can support the verification process during disasters and emergency situations. For example, the length of tweets, the sentiment of words, the numbers of hashtags, emoticons, and retweets provide indications on a tweet's credibility [47]. Another feasible option is to put the location of a message in relation to the general spatial distribution of the same and other VGI outlets and to assess the credibility using a probability model [48]. The same goes for messages, and tweets in particular, that include links to photos and videos. The language can also be used to determine whether that multimedia content is credible or not. Taken together, these criteria provide the parameters to predict the accuracy of tweets and other social media content. One particularly important aspect is the need of verified information during the situation assessment phase and the ability for practitioners to be able to evaluate social media contents [49].

Concerning practical applications, these findings were used to develop a “Credibility Plugin” for Twitter. Moreover, several studies have investigated the reliability of Twitter as an information source and automatically detecting deceptive tweets [26], [34]. Further tools and platforms focus on the collection and manual processing of contributed data. During the aftermath of the earthquake in Haiti, Ushahidi platform was used to map power outages, contaminated water, and requests for food, water, shelter and medicine [8]. After the Earthquakes in Kathmandu (2012) and Central Italy (2016), Ushahidi was one of the most used platforms [50]. SensePlace2 is another map-based web application that integrates multiple text sources (news, RSS, blog posts) and transfers them into features on a map [51], [52]. Then, emergency responders can easily filter accidents by place or time and perform analyses by changing issues and perspectives. The web platform CrisisTracker integrates automated real-time analysis of crowdsourced data with the goal of increasing situational awareness during disasters [53]. It rapidly annotates streams of unstructured tweets with metadata and group related content. Similar tools are TweetCred [33] and Tweak the Tweet [54].

All these applications show a common primary focus on the textual content. However, text messages and reports have an induced subjectivity, which causes difficulties in verifying the data and challenges its proper use [55]. Besides the textual content, social media messages contain an increasing amount of photos and videos, coining the term *social multimedia*. While text is rather subjective, photos and videos taken on-the-ground are considered to be more objective and more reliable [56]. As the interpretation is left to the viewer, a disaster professional can infer critical information from a photo, which a short textual description might not able to communicate. While photos can provide a higher information depth, they still need to be verified and structured. It is also critical to select those photos providing valuable information.

In this paper, we address the gap of verifying social *multi*media content during ongoing disaster events. Citizens and volunteers are considered as valuable source of information, but they are not integrated beyond that. We present an approach to make them active participants in the information processing and enhancement. Digital volunteers do not only act as information provider, but they will also review, structure and enrich geospatial information provided by the crowd. We developed a conceptual framework to leverage the available sources of social multimedia for information assessments of relief organizations by integrating volunteers in a streamlined, collaborative process. This framework fosters the incorporation of human intelligence by focusing on simple manual interaction.

3. CONCEPTUAL FRAMEWORK

In this section, we present and describe a conceptual framework to leverage crowd-sourced social multimedia from various sources for information assessments during disaster response actions. It focuses particularly on addressing the drawbacks of missing validation, verification, and aggregation of social multimedia items. The framework aims to utilize the often-demonstrated ad-hoc volunteer help of citizens and let them collaboratively process photos and videos. The processed results will be integrated into geovisualizations for disaster managers and professional responders and enable spatial access to the social multimedia items. The framework follows a computer-supported collaborative processing approach. The idea is to combine the strength of human intelligence with machine computing to allow collaborative processing by ad-hoc volunteers. Every step is performed semi-automatically, which minimizes the workload for the user but keeps the full potential of human processing. Figure 1 illustrates the three stages of the framework: Input, User Processing, and Usage.

The *Input stage* provides automatic methods for monitoring different sources and for retrieving multimedia content, potentially related to a specific event. For each source, a dedicated adapter manages the connection, e.g., a Twitter or Facebook connector, or a generic website harvester. After retrieving potentially related content, a filtering process mitigates the volume of information produced by the crowd. For example, the information sharing within and across multiple sources results in duplicated content of the same multimedia items. Those duplicates need to be removed or merged to trace the primary information. Due to the multiplicity of sources, the retrieved multimedia items are present in a variety of formats and structures. To unify the volume of information, this framework provides a coherent view of the items through a central message object. This message object consists of a set of core and extended attributes. The set of core attributes is identical for all incoming social multimedia items across the variety of sources. It contains eight elements:

- title
- textual description
- date and time of creation
- source
- sender
- multimedia content
- location
- tags

The set of extended attributes contains all further source-specific information and metadata, such as the number of likes, comments, retweets, links to photo collection, etc. The retrieved information from the different sources must be mapped to this message object. This mapping is individual for each source and is specified in the adapters. If a core attribute cannot be filled in (i.e., a social media item does not contain a geolocation information, or no tags are found in the item), the corresponding attributes are set to null. Messages with duplicated content are merged, which requires to resolve potential conflicts of the time, source, and sender, or even to trace back the sharing and forwarding history of information (e.g., retweeting and sharing of information).

Within the input stage, an automatic filtering distinguishes between messages from trusted sender and content from the general crowd. The introduction of this reputation filtering and annotation was suggested by disaster officials during expert interviews as part of the evaluation (cf. chapter 5.1) The messages are filtered automatically according to a list of trusted persons or social media accounts and will be annotated with a reputation attribute. This list needs to be adapted for each event and can be dynamically extended or limited during the event. The list of trusted senders may include accounts of official members from relief organizations, crisis managers, or further domain experts. Also, any other person or online account can be assumed as reliable and trusted source, even if the real identity remains unknown. Besides a manually maintained list of senders, the reputation filtering and annotation step can also incorporate automated, self-learning approaches to estimate the trustworthiness of user contributions

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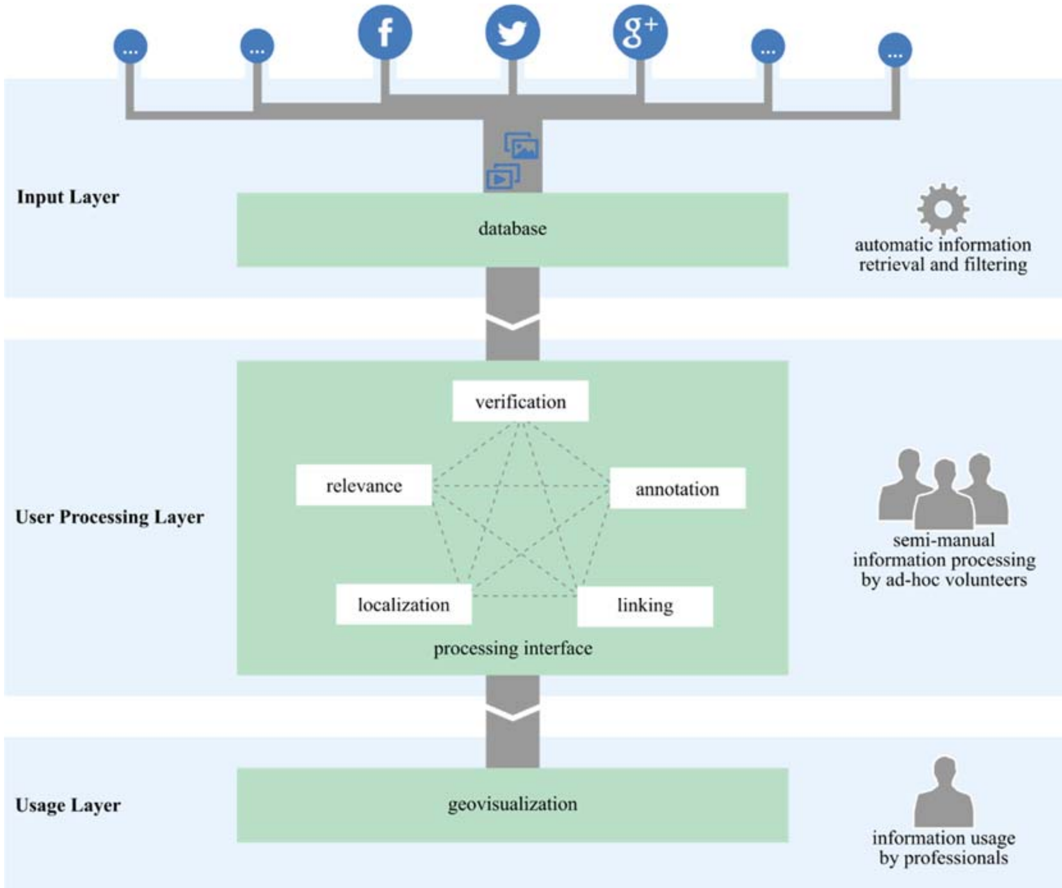

Figure 1: The Conceptual Framework Describes A Three-Tier Process To Leverage Crowd-Sourced Social Multimedia For Information Assessments During Disaster Response Actions. It Consists Of The Three Stages Input, User Processing, And Usage.

based on common user rating principles from the results of the user processing stage. All messages, annotated automatically as trustworthy, are assumed to be true, reliable, and more relevant. Therefore, they receive higher rankings for the computation of a relevance score (cf. User Processing Stage).

The *User Processing Stage* is the central part of the framework and creates qualified information from the filtered, but still raw messages. As the outcome of this stage, the social multimedia items are returned as messages with added value. They contain a relevance score, which identifies the usefulness of the message for information assessments. In contrast to the automated retrieval and filtering in the previous stage, the processing in this stage is performed manually by users. The work is not intended to be dispatched to professional users or members of an aid organization, but primarily to ad-hoc volunteers. Experts or professional users are educated and trained in the field of disaster response, but they have limited resources and availabilities for additional workload. The framework involves lay persons as digital volunteers in the processing to achieve a higher scalability. These ad-hoc volunteers mostly have no prior training or knowledge about disaster management but show a high motivation to support relief actions. To counterbalance the lack of knowledge and experience the User Processing Stage is split into five steps, which contain simple tasks to be performed for each social multimedia item. This way the digital volunteers take over the main work without having to be trained extensively or needing to become acquainted with the subject themselves beforehand. The five steps are:

- Verification
- Prioritization
- Annotations
- Localization
- Linking

The five steps do not have to follow a sequential order but can be performed in any order. Each message is processed by several users with each of them providing individual processing results. The results of verification and prioritization are recorded as numeric values, which are then used to compute an overall and jointly created relevance score for the message. Volunteers do not see the results of other user's vote for verification and prioritization. However, the annotation and localization are a collaborative effort, where a volunteer can continue work of other volunteers. The number of necessary volunteers per item can be defined individually for each event or be also adjusted automatically depending on the statistical distributions of the responses.

The *Verification step* confirms the authenticity of a message. This step is necessary as some information posted online is simply wrong for a variety of intentional and unintentional reasons [57]. This step identifies potentially false or misleading information. If the message receives a critical amount of negative verification and falls below a given threshold, it will be discarded from further processing by other users. Messages from trusted sources can skip the verification step as they are assumed to be true and reliable. However, if they undergo the same procedure than other messages, their ranking is still higher and discarding them requires more votes.

The *Prioritization step* indicates if a message is related to the event at hand and if so how useful it might be for relief organizations. Messages with a higher prioritization ranking will be visualized in a more salient and more prominent way in the usage stage, while lower priorities result in peripheral depiction.

The *Annotation step* facilitates tagging each message with further useful information, such as categorization or adding keywords. Here existing tags, which are extracted automatically in the input stage, can be added and extended by the volunteers.

The *Localization step* refers to the validation of an existing georeference or the addition of a missing one. This step can use existing, but rather imprecise location information (e.g., a geotag) and extend it by specifying the position more precisely. The step can also describe the visual content, e.g., marking which building is shown and describing it in more detail. In contrast to the prior votings, the outcome of each user contribution is not handled anonymously but directly shown to other users. Therefore, the georeferencing is a jointly achieved, collaborative effort. %issue of disagreement is not taken into consideration

The *Linking step* creates clusters of related messages. Such clusters reduce the amount of visible content and organize messages. Within these clusters, more relevant messages are placed more prominent and salient than less relevant messages. The clusters can be created based on spatial properties, but may also be based on other criteria, such as keywords, time or the information source. While this can be done automatically, volunteers can also link one message to another and take over its annotations or localizations.

At the end of the *User Processing Stage*, the social multimedia items have been transferred from single, raw message objects to a set of processed, prioritized and spatially annotated messages. This set provides a more holistic information source.

The final *Usage Stage* provides disaster officials with a map-based view on the disaster-related crowd-sourced multimedia items relevant to the event at hand. It supports them in reviewing the most relevant messages, which are reliable and accurately located. Instead of skimming through vast amounts of retrieved multimedia items, decision-makers can directly access the photos and videos that are potentially most important. This stage provides map-based geovisualizations and tools to enable the spatial access to the multimedia items.

This conceptual framework describes the core working principles for a modular set-up. The three stages of the framework describe a processing pipeline for social multimedia items that turns them from raw data into a set of useful information with added value. The stages follow the idea of a modular architecture. From a technical perspective, each stage should be encapsulated and use clearly defined interfaces. Similarly, each step in the User Processing Stage should have explicit interfaces. Such modular design allows for integrating the framework in existing information systems and organizational structures. Each stage and all steps can be extended or realized in a more or less complex way. For example, the georeferencing can provide a precise geotag, include orientation information or infer the geolocation based on marked features in the image [58]. The proposed conceptual framework aims to facilitate information assessments by effectively integrating crowd-sourced multimedia. Automated approaches collect social multimedia items from selected sources and prepare them for processing by ad-hoc

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volunteers. As a result, disaster officials continuously receive a set of verified, prioritized and interconnected photos and videos with a geospatial reference depicting an on-site situation as perceived by the crowd.

An earlier version of the framework has been evaluated by three experienced disaster officials (cf. chapter 5.1). Their feedback has led to the revised version as described here. In the next section, we will explain how the framework can be realized and demonstrate the functionality with Twitter as an example source for social multimedia.

4. DEVELOPMENT OF A PROTOTYPE

Based on the conceptual framework we designed and developed a prototypical web application called DisasterMapper. This section will explain the key aspects of the implementation of the prototype and outline the key elements in the realization of the conceptual framework.

4.1. System Overview

DisasterMapper is designed to enable volunteers to annotate and enrich information harvested from social multimedia during disaster situations. Therefore, the application is tailored to an incident and involves two different user groups: professionals and volunteers. Professionals are trained staff members from aid organizations or disaster management agencies. Volunteers are laypersons, offering their help on an ad-hoc basis. They mostly come without prior training but have an intrinsic motivation rather than a formal assignment to help. This distinction is also reflected in the application.

Our prototype consists of a front-end and a back-end component. The automated back-end component constantly retrieves messages with photos from social media outlets and prepares them for manual crowd-based processing by volunteers. As an example, media source, we chose Twitter. The front-end component consists of two user interfaces (UIs), each with two coordinated views. One UI enables volunteers to process the multimedia messages following the five steps of the *sense-making and processing stage*. The second UI realizes the *interaction and geovisual analytics stage* for the disaster officials, who are making use of the processing results.

To realize to user processing approach, DisasterMapper was designed for a web browser and utilizes several JavaScript libraries: Leaflet[2] for mapping utilities, OpenStreetMap[3] for map tiles, jQuery[4] for DOM utilities, and Bootstrap[5] for styling.

4.2. Deployment Principles during an Event

DisasterMapper can be applied to any large-scale emergency but was specifically designed for natural disasters affecting a large area over an extended period, such as floods, typhoons, or earthquakes. In those situations, people show a particular social cohesion and solidarity and demonstrate an intrinsic motivation to help [59], [60]. DisasterMapper channels this motivation by providing an opportunity to help as a digital volunteer.

The professionals will deploy, maintain, and administrate the system, and they will use the crowd-sourced multimedia for information assessments in the usage stage. Some professionals will also act as gatekeepers and moderators. At the onset of a disaster incident, a professional aid worker creates a new event in DisasterMapper and initiates the retrieval of multimedia items based on pre-defined criteria, including an identifier for the incident (e.g., the name of a storm), keywords, the area of interest, and start-time. The backend then starts to continuously collect Twitter messages and opens the user interface to the general public. If a list of trusted persons (i.e., Twitter accounts) is available, each message will be automatically checked against it and assigned a trustworthiness factor. These actions are performed automatically and realize the Data Retrieval and Storage Stage as well as the Reputation Stage of the conceptual framework.

After setting up an event in DisasterMapper, the volunteers can perform the processing work on the collected items. The processing steps of the User Processing Stage are broken down into small tasks for simple and easy completion. This part of the application follows a crowd-tasking approach and aims for numerous contributions. Each volunteer receives messages in a sequential order. Each message holds a photo and requires individual visual inspection. Here, the volunteer has simple voting options and means for interactions according to the five steps of the framework. After performing the steps, the volunteer submits her contribution, which is then used

[2] http://leafletjs.com (visited 09.08.2018)
[3] http://wiki.openstreetmap.org (visited 09.08.2018)
[4] https://jquery.com (visited 09.08.2018)
[5] http://getbootstrap.com/ (visited 09.08.2018)

to prioritize and visualize the messages in the Usage Stage.

Professionals and disaster officials can log into the same event and have a similar interface. However, their view contains the result of the volunteering contributions in a ranked and prioritized order. The messages can be queried and explored in a more structured way using the map interface to facilitate the decision-making regarding response actions.

The following sections describe the implementation of each stage with an emphasis on the user interfaces.

4.3. Implementation

Our prototype follows an MVC pattern and is subdivided into a front-end and a back-end component. The back-end component collects tweets for each ongoing event based on a set of defined criteria, including the time range, the spatial extent, a list of keywords, and optionally a list of user profiles, which are considered trustworthy. The collected tweets are translated into a message item with the six core properties of title, textual description, date and time of creation, source, sender, and media content. Each property is specified in more detail and contains references to the information source.

The messages are JSON-encoded and stored in a MongoDB database. Unlike relational databases, this NoSQL database does not enforce a schema or predefined structure. Therefore, retrieved objects can be stored more flexibly. In MongoDB, records are called documents and organized in collections.

Listing 1 shows a JSON encoded example document from the collection "*messages*". Each message contains the reference to a specific event (cf. attribute "*event*") and includes the core properties, the user contributions as well as derived scores. All user contributions are collected in a nested object with the votes from all users. Each user contribution refers to an author and contains a timestamp as well as the base elements "*verification*", "*relevanceScore"*, and "*category"*. If a message is considered by a user to be not valid the value for "*verification*" is set to false, "*relevanceScore*" to zero, and "*category*" is left empty. If a user considers the message to be valid, she can provide a relevance score, assign it to a category and include further information such as the location of the tweet as a pair of latitude and longitude, links, keywords, and a comment. When submitting the user contribution, the derived scores are updated. The attribute "*verified*" indicates if a message is valid and reliable. It is automatically "*true*"' if it originates from a trusted source (cf. Attribute "*trusted-Source"*). Otherwise, it is computed based on the user contributions and the values for "*verification*".' If a defined threshold is exceeded, the attribute "*verified*" is set to false, and the message will not appear in the decision maker's view. If the message is verified, a ranking score is calculated. In this prototype, we used the mean value of the "*relevanceScore*" from all contributions. If two messages have the same relevance score, the one with the lower standard deviation receives the higher ranking. Higher ranking scores result in more prominent visualization for the disaster officials.

4.4. User Interface

The web front-end is the central component of the application and has been realized in two separate, but complementary, user interfaces (UIs): one for digital volunteers to provide their contributions efficiently to the messages, and one for disaster officials to visualize and filter processed data according to the "*visual analytics stage*". All users need to log into the application. Upon registration, each user is a digital volunteer at first. Disaster officials are being upgraded by the system administrator.

Figure 2 depicts the UI for digital volunteers, containing two coordinated views. The map shows the affected area and provides spatial access to already geolocated messages. A list view on the left side contains all available messages in an ordered by recency from more current to less current. Selecting a message from either the map or the list will result in an aligned view: the map zooms and pans to the location of the message or the list scrolls up or down to provide the message's details. The map extent also serves as a bounding box for a spatial filter of the messages. Georeferenced messages, which are not within the view frame of the map, are not included in the message list on the left. Non-geolocated messages are included permanently in the list, as they still need to be assigned to a location.

A message itself consists of two parts. The upper part provides the details of the message, including the author, the creation time, the text, the included media (i.e., photos), and an identifier if the message is already geolocated (cf. Figure 2 (c), blue area on the left). If a user clicks on the media item, it will open as an enlarged overlay on top of the map area. The lower part of each message allows digital volunteers to make contributions to the message. This part becomes visible if a particular message is selected. The volunteer can first vote regarding the credibility and the relevance of the message and can assign it to a predefined category. Upon selecting one voting option, the volunteer receives a visual feedback following the three traffic light colors, with "green" representing a high relevance/ credibility, "orange" a mid-level value, and "red" a low relevance/ credibility. These votes are made secretly and will not be shown to other volunteers to prevent any bias as each vote accounts for the calculation of the relevance scores. For the keyword and comment section, the volunteers provide written input. In contrast to the votings, this section and the contributions are made public and become immediately visible to all volunteers. Finally, if a message is not yet georeferenced volunteers can drag a marker onto the map to locate the message. The bar at the top of the screen includes opportunities to filter messages by certain criteria such as spatial or temporal extent, keywords, media type. A short introductory tutorial before using the application will provide the digital volunteers with short guidelines regarding the votings on relevance and categorization.

The user interface for disaster officials is designed very similarly to the one for digital volunteers. The alignment of the map, the message list, and the filter bar are identical. In contrast to the volunteers, the disaster officials see the messages in the list on the left side, not in a temporal order but prioritized according to the computed relevance score. Therefore, they see the most important messages first but have still access to all messages. Clicking one message provides an overview of all volunteers' contributions: the number of people that have voted a message as credible or implausible, the category, which the message was assigned by the majority of votes, the keywords, and comments inserted by volunteers. Additionally, the search function allows querying messages based on their verification and relevance score, as well as by category. The map section also defines the spatial query extent. Disaster officials can enable real-time monitoring to receive immediate updates on newly processed messages. If this function is disabled, the application does not update the


```
{
  "_id": "654b335eaa71326383e64004ffa82bad",
  "sender": {
    "name": "Mister-X.it",
    "profileImage": "https://pbs.twimg.com/profile_images/
        1127509121/Untitled-4_400x400.jpg",
    "url": "https://twitter.com/RedazioneMrX"
  },
  "title": "Tweet",
  "text": "Terremoto,lo sciame sismico non si ferma.
        Scossa di 4,8 nuovi crolli. Oltre 22mila persone
        assistite http://dlvr.it/MZTbZZ",
  "createdAt": "2016-11-02T06:07:11.000+0000",
  "source": {
      "name": "Twitter",
      "url": "https://twitter.com/RedazioneMrX/ sta-
        tus/793680824054849537"
  },
  "media": [
      "https://pbs.twimg.com/media/CwO4gBqVUAAVsmy.jpg"
  ],
  "location": {
      "longitude": "43.037685",
      "latitude": "13.164240"
  },
  "event": "5461fd60aa75cea81500003d",
  "relevanceScore": "2.8",
  "relevanceScoreStd": "1.47",
  "verified": true,
  "userContributions": [
    {
      "relevanceScore": "4",
      "verification": "true",
      "category": "People",
      "keywords": [
        "sismico", "Fiastra"
      ],
      "author": "5483065aaa75ce581300002e",
      "createdAt": "2016-11-02T09:07:11.000+0000"
    },{
      "relevanceScore": "3",
      "verification": "true",
      "category": "People",
      "comments": "Da verificare la presenza di individui
        nei veicoli.",
      "keywords": [
        "Earthquake", "Italy", "Bolognola"
      ],
      "author": "5483065aaa75ce5813000030",
      "createdAt": "2016-11-02T09:13:26.000+0000"
    },{
      "relevanceScore": "4",
      "verification": "true",
      "category": "People",
      "longitude": "43.037685",
      "latitude": "13.164240",
      "links": "http://dlvr.it/MZTbZZ",
      "keywords": [
        "terremoto", "Italy", "Fiastra"
      ],
      "author": "5483065aaa75ce5813000031",
      "createdAt": "2016-11-02T09:13:56.000+0000"
    },{
      " relevanceScore": "0",
      "verification": "false",
      "category": "",
      "author": "5483065aaa75ce5813000032",
      "createdAt": "2016-11-02T09:17:28.000+0000"
    }
  ]
}
```


Listing 1: Example Of JSON Encoded Message Object. The Individual User Contributions (Indicated With Yellow Background) Are The Basis For Computing The Relevance Score, Its Standard Deviation, And The Verification Indicator (Indicated With Green Background).

content itself and therefore remains more invariant. The user then needs to pull new updates manually, which in some cases is preferred over a continuously

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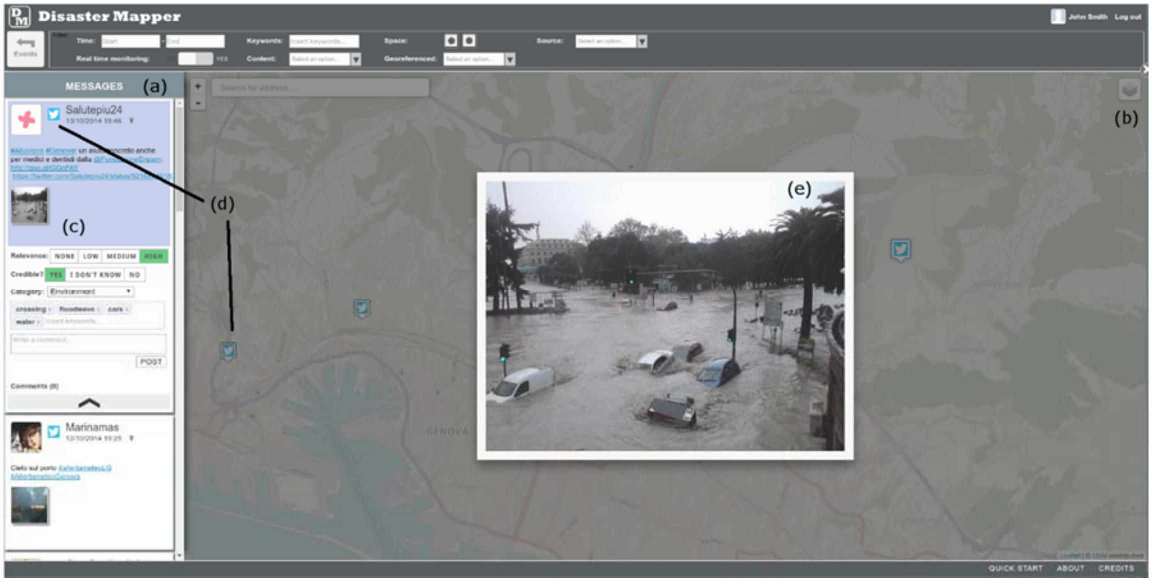

Figure 2: Screenshot Of The Disastermapper Prototype With A Digital Volunteer Processing A Message. On The Left Side (A) All Available Messages Are Listed According To The Filter Settings And In Temporal Descending Order. Only Messages In The View-Shed Of The Map (B) Are Listed Here. The Current Message (C) Is Indicated By The Symbol Of Its Source (Here The Twitter Logo), Both On The Map And The List (D). The Media Item Opens In An Overlay On Top Of The Map (E).

self-updating system. The disaster officials can also download the georeferenced and prioritized messages as shapefile to integrate them in other GIS applications.

5. EVALUATION

Our proposed framework and the developed prototype have been tested and evaluated in two types of evaluation. The first one focused on the theoretical framework and consisted of three semi-structured expert interviews, while the second evaluation relied on a real-world experiment to evaluate the prototypical application with volunteers and disaster officials.

5.1. Expert Interviews

To review our proposed conceptual framework, we conducted problem-centered interviews [61] with three professional disaster officers. One was a chief fire officer in the province of Perugia in the Umbria region of Italy. The other two were head officers in the Civil Protection Departments of the Tuscany and the Abruzzo regions of Italy. The interviews were conducted in Italian language and recorded on tape. Then the recordings were transcribed and translated into English. For the interviews, an earlier iteration of the framework was used. The feedback from the domain experts and practitioners was included in the revision of the framework as it is presented here.

All three disaster officers emphasized the potential benefit of social multimedia can be far bigger than its actual impact, especially in the early phase of a disaster. However, the lack of trained people prevents the incorporation of these information sources. Outsourcing the processing to ad-hoc volunteers was acknowledged as a valuable opportunity, but all three participants expressed hesitations and concerns. One expert stated that “[usual] data processing requires knowledge and expertise, which exceeds the typical citizen capabilities”. This concern can be counterbalanced by the five-step approach to processing each message. Instead of a generic task requiring profound knowledge and prior training, we apply the principles of micro-tasking and split the processing into small chunks. This approach minimizes the error rate and maximizes the user involvement [62].

The second important consideration relates to the trustworthiness of authors. Pictures taken by trained people and shared through social media networks were assumed to be more trustworthy than other messages. In contrast to the general crowd, information from trusted sources does not require the same validation and verification may be separated. Based on this feedback we introduced the “*reputation filtering and annotation*” step in the input stage, which labels the messages from trusted persons such as members of relief organizations, crisis managers, mayors, or further domain experts. These messages

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may be more trustworthy, but not necessarily more relevant. Therefore, all messages will undergo the process (including the verification step) but labeled messages will be presented to the digital volunteers with higher priority to be processed first. Compared to other messages these trustworthy ones are also ranked with higher final relevance scores, resulting in a more prominent presentation to the disaster officials.

The third consideration refers to the content of the messages. It was considered necessary by the three experts to distinguish between requests for help and the provision of information about, e.g., the state of buildings or roads. While one can directly save lives, the other one is necessary for planning where to send relief teams and where to place the base-camps. The DisasterMapper prototype realizes this requirement by assigning the messages to categories during the annotation step. The categories are "requesting help", "providing help", "information provision" and "other". The expert interviews provided valuable feedback, which gave many insights from the practitioner's point of view and led to the revised and extended version of the framework as we present it in this paper.

5.2. Experiment

To test the applicability of the framework and its prototypical realization, we conducted a small practical experiment involving digital volunteers and disaster officials. As a use case, we selected a prior incident, namely the flash flood event in Genoa, Italy in early October 2014. Within three days the city had experienced 180~mm of precipitation, which is equivalent to two-thirds of the average annual rainfall. The resulting massive floods caused one death and damages to public and private property of about EUR 185 million. The incident had also entailed massive social media activities, with many messages being created and shared through different networks. We conducted our experiment with 20 participants from Italian relief organizations. They took over the roles of the volunteers and disaster officials. The study was divided into the three phases: briefing, work phase, and questionnaire.

The briefing phase introduced the participants to the experiment. The use case and the tasks to be performed were presented by two researchers, who also supervised the experiment. The participants received guidelines on how to evaluate the messages regarding their verification, relevance, category, and main keywords. In preparation for the experiment, a subset of messages had been selected and processed by our researchers together with the three interviewed experts (cf. chapter 5.1). During the work phase, the volunteers were processing the messages of this subset. The disaster officials were working on a fictitious information assessment and constantly included the processed messages. Additionally, the researchers were directly observing the ongoing processes. The third phase consisted of the questionnaire and aimed to collect verbal feedback from the participants. This feedback was collected in an intentionally informal way to gather unaffected opinions. The questionnaire consisted of four parts: demographic information about the participants, their technology skills, their use of IT systems during response actions, and the ease of use of the application.

All participants were active members of the Italian Civil Protection, most of them (90\%) for more than one year and 60\% for more than five years. Eight participants were between 18 and 30 (40\%), six par-

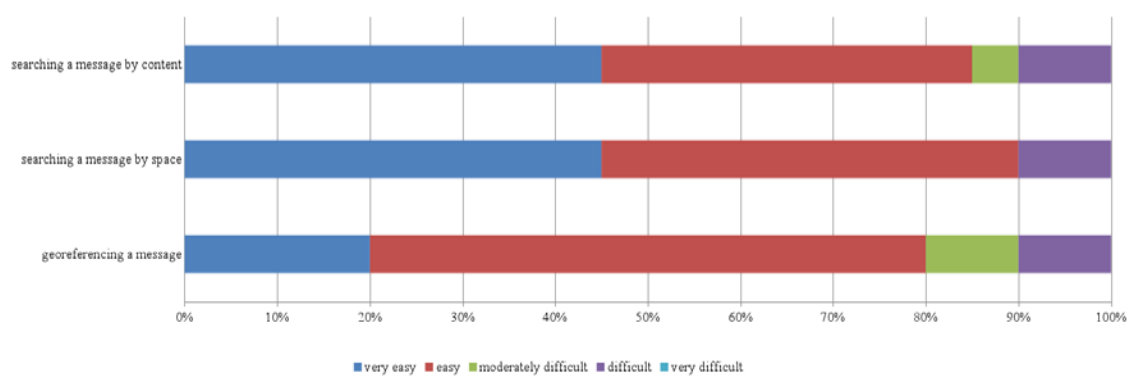

Figure 3: Results Of The Questionnaire Regarding The Ease Of Searching For And Georeferencing Of Messages. Searching For Messages Based On The Content Was Almost As Easy As Searching For Messages Based On The Spatial Properties (E.G. An Existing Georeference). Georeferencing A Message Was Also Reported To Be Easy.

ticipants were between 31 and 50 (30 %), and another six participants were over 50 (30 %). Most participants were male (65 %).

The participants reported to not having encountered difficulties in completing the requested tasks. All tasks were considered easy or very easy to accomplish. Figure 3 shows a histogram of the questions regarding the ease of searching for a message by content and by space and the georeferencing of a message. Both types of searching for messages were easy to accomplish, with slight favors for the spatial search. The georeferencing of a message, i.e., placing a marker on the map at the location, was also reported to be easy. However, some participants mentioned, it was challenging to identify the location of a photo if the message did not contain detailed information, e.g., in the textual description or by recognizable landmarks in the photo. The georeferencing also became challenging, if the volunteers lacked local knowledge. The involved participants were mainly from the Abruzzo region und were facing difficulties in processing messages about the flood event in Genoa, which is several hundred kilometers away. It follows from these statements that a good knowledge of the affected area is preferable and, hence, it would be desirable for real-world deployments to involve local digital volunteers. Moreover, a few participants mentioned it to be difficult to verify the message if the accounts could not be clearly related to a person. We observed the participants opened the tweets on Twitter and inspected other tweets from the same account. It was requested to better facilitate this activity by the DisasterMapper application. The participants acknowledged the provided evaluation schema as very helpful. However, it should be introduced by the application itself and not through an external briefing. This would decrease the obstacle for ad-hoc volunteers.

The participants in the role of disaster officials were also able to utilize the processed messages and could incorporate them into the fictitious information assessment. The participants requested the opportunity for disaster officials to modify the event description and specifications during deployments to be able to adapt the processing to the changing needs. For example, the participants wanted to modify the evaluation schema, i.e., adapting the categorization, or prioritize certain areas to be processed first.

6. DISCUSSION

The conceptual framework describes how social multimedia can be turned into a structured set of valuable messages for information assessments. This framework has been reviewed by three expert interviews and prototypically realized in the DisasterMapper application. This prototype primarily aimed at testing the feasibility and applicability of the framework as a whole. We, therefore, restricted our focus to the central aspects of the User Processing Stage and the user interfaces. The main development was done for the digital volunteer's UI with adaptations for the disaster officials UI. Although the officials could make use of it in the usage stage and have done so successfully, this user interface does not exploit the full potential of the framework. The evaluations proved the overall feasibility of the framework, but there is a need for a closer inspection of all steps and an explicit evaluation of the usability und user experience. The linking of messages has not been made explicit but is based on geospatial properties and can be explored through the geovisualization. Further types of manual or automatic linking and grouping of messages should be explored and tested. Here, a stronger focus on the needs of disaster officials is necessary to adapt their user interface accordingly.

Although all tasks of the experiment were easy to perform for the qualified and experienced participants, their feedback shows the need for further exploration and analysis of spatial interaction and contributions methods for laypersons. Any additional barriers preventing immediate contributions should be removed or lowered as much as possible. The need to sign-up for the application is such a barrier. It was introduced because in related crowdsourcing applications the contributions of registered users were of higher quality than those by anonymous users [63]. Despite the need for this mechanism, future work will design a simpler and more immediate sign-up and log-in process. The integration of authentication methods such as OAuth logins for prominent social networks will make DisasterMapper more accessible for the users and will also allow the disaster officials to know more about the volunteers.

Future work also aims at investigating which different roles the volunteers adapt during their participation and how trustworthy the processing results of volunteers are. The contributions of more trustworthy and known volunteers may also have a higher weighting in the computing of the relevance scores than those of first-time digital volunteers. The experiment revealed the lack of local knowledge as important and limiting drawback. To counterbalance this issue, we plan to assign the volunteers according to their spatial knowledge areas. Users may provide zones of familiarity and will receive messages for

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processing and revising from within or close-by these zones.

One major limitation of the application is given using Twitter as the only outlet for social multimedia. Although it provides a valuable source of crowd-sourced information and its broad penetration [40], there are regional differences, which result in a partial state of coverage. Future work needs to incorporate further sources for two different reasons. First, the application needs to increase the information coverage of social multimedia. Second, the interplay of several outlets and the merging of messages with duplicated content have not been realized in our prototype. For future work, we will also incorporate videos as second major multimedia type in social networks. We will explore how these videos can be properly georeferenced and which means of interaction are suitable to enhance assessments.

7. CONCLUSIONS

Information assessments during disaster response operations need detailed and timely information to correctly evaluate the situation after a disaster strike. Crowd-sourced information and social multimedia, in particular, can provide valuable information to disaster officials if it can be incorporated systematically without additional efforts. However, crowd-sourced information is usually not well structured and leveraging its benefits requires efforts and resources relief organizations usually do not have.

In this paper, we aimed at leveraging crowd-sourced social multimedia by following a semi-manual micro-tasking approach to process collected social multimedia. We developed a conceptual framework, which addresses the identification of potentially relevant multimedia messages and their preparation for a rapid information assessment. The framework utilizes the often-shown intrinsic motivation of ad-hoc volunteers and enables them to help digitally by verifying, georeferencing, and annotating photos collected from social networks or other non-authoritative sources. The conceptual framework consists of three stages, each of them constituting a phase to be traversed in the process from raw social multimedia messages to useful items for information assessments. During the central "*Sense-Making and Processing Stage*" and a series of five steps, the digital volunteers make small and well-structured contributions to the raw messages. With these contributions, the volunteers verify and prioritize the messages according to a given schema. They can geo-reference the messages by placing a marker on the map and assign the messages to categories to identify the most important and urgent ones.

We implemented a prototype, namely DisasterMapper, which realizes the developed framework. Compared to similar platforms such as CrisisTracker [53], TweetCred [33], or Tweak the Tweet [54] the provides a unique and novel combination for the user-driven assessment of verification, geolocation, and prioritization. DisasterMapper enables digital volunteers to contribute to response actions by processing collected social multimedia items related to an ongoing emergency. All manual contributions are summarized into an overall score by automatic means. The prototype allows disaster officials to use the annotated information for information assessment.

We conducted three semi-structured interviews with disaster officers and tested the overall approach in a real-world experiment. Both evaluations demonstrated that digital volunteers could successfully process social multimedia content and create a valuable set of photos, which can then be used systematically for information assessment operations. Citizens are not only pure information providers anymore but can become active participants in the information processing and enhancement.

The conceptual framework provides a generic summary of necessary actions and steps for a structured integration of social multimedia. Our DisasterMapper prototype illustrates how this framework can be realized and demonstrates the interaction between disaster officials and digital volunteers. The prototype needs to be extended and revised within a second iteration to fully play out the advantages of the framework. Future work will address the discussed limitations and increase the usability of the user interfaces and extend the prototype to also incorporate videos from social networks showing real-world scenarios.

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