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A Visual Communication Language for Crisis Management

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***Abstract*- In crisis situations, decision-making capabilities rely on reports from all parties involved. For achieving the necessary capabilities of crisis technology, a communication-interface prototype representing concepts and ideas has been developed. To support language-independent communication and to reduce the ambiguity and multitude of semantic interpretation of human observers' reports, the messages are constructed using a spatial arrangement of visual symbols. We developed a dedicated grammar to interpret and convert the visual language messages to (natural language) text and speech. The communication interface also provides an icon prediction to have faster interaction in next icon selections. The system processes the incoming messages to build a world model by the employment of ontology. A blackboard structure in a Mobile Ad-Hoc Network is used to share and distribute information. We deployed our visual language interface in a serious game environment of a disaster and rescue simulator. The current implementation of this environment is capable of simulating real disaster situations using information from human user observers' reports.**

***Index Terms*—Crisis management system, visual communication language, natural language processing, disaster simulator.**

1. INTRODUCTION

Recent crisis events have shown that existing communication infrastructures can become overloaded or even breakdown. The need for crisis-management technology to cope with nondeterministic environments resulting from the global wired-communication breakdown has never been more apparent. The terrorist strikes against U.S. targets on September 11, 2001, for example, have disabled the crisis management services that provided information support service for rescue teams, victims, witnesses and families [13]. This type of major incidents generally involves much information and operational chaos. In such situations, personal devices, such as Personal Digital Assistants (PDAs), which offer both portability and wireless interfacing, may be available for communicating.

PDAs typically offer a small set of user-interaction options limited by small sized touch screens, the number of physical buttons and (for some PDAs) small sized keyboards. Although some researchers have proposed mechanisms for adding multimodal capabilities, for example [9][12][41], the current speech input technology is still less suitable for mobility. The environment in which the technology is used should be the same as the training environment of the system [6], whereas PDAs are often used in various environments under various conditions. In many cases, this results misrecognition of commands, which is frustrating to the user. This leads us to aim at a natural interaction style based on GUI for communication.

Observation reports during crisis situations must clearly describe events in order to facilitate effective problem solving and prevent further damage. In our view, data that observers sense in a crisis location is transformed into reports for others using their mobile devices. Although speech and text communication are commonly used for reporting any events, the descriptive meaning of these modalities misses a more direct mapping with "real world". These types of communications demand or afford more reflective thinking as one must constantly update one's mental model of the spatial relation [32].

Human's observations are context sensitive. They are based on multimodal input in a given context. One's observations may be affected by one's emotional state and mood. Such knowledge, belief and opinion are personal, and conceptual. In the process reporting observations, the information may become ambiguous, incomplete and language dependent. In addition, human observers are typically remote in both time and place. The lack of standard communication representation hinders information sharing during crucial emergency situations [13]. In order to facilitate the exchange of information, to promote universal understanding, and to adequately address the communication of mission critical information across different disciplines and cultures, a common representation for communication needs to be developed [38]. The meaning of the various information objects, their interrelationship, and their potential relevance in crisis situations have to be agreed by multiple users who are working collaboratively in resolving crisis. Related theories and concepts from semiotics have been selected for a communication representation by (an arrangement of) icons.

Icons have been investigated for representing concepts that are objects, actions or relations [34]. Concepts are used in human communication for representing internal models of human themselves, the outside world they perceive, and anything with which they interact. By virtue of resemblance between a given icon and the object or the movement it stands for, an icon functions as a means of communication and offers a direct method of conversion into other modalities. As icons offer a potential across language barriers, any interaction using the icons is particularly suitable for language-independent context. Furthermore, direct icon manipulation allows faster interaction to take place [22]. As pictorial signs, they can be recognized quickly and committed to memory persistently [15]. Therefore, icons can evoke a readiness to

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respond for quick exchanges of information and promote quick ensuing actions [27].

It is possible to define a language based on icons [8], i.e. a visual language, where each sentence is composed by a spatial arrangement of icons. Each icon represents meanings. An individual icon can be interpreted by its perceivable form (syntax), by the relation between its form and its meaning (semantics), and by its usage (pragmatics) [7]. To cope with the ambiguity of meaning represented by an icon, the meaning of every icon is defined by a predominant word or phrase created according to metaphors fitting a given context. Since icons are representations of models or concepts, with which humans are actually interacting, we expect this language to be easy to learn. Once a set of iconic representations is established, increased usage may lead to more stylized and ultimately abstract representation, as has occurred in the evolution of writing systems, such as the Chinese fonts [10]

We designed a communication infrastructure using a visual language interface in a Mobile Ad-Hoc Network (MANET) for supporting people who must work collaboratively for resolving crisis. These people are rescue teams (that are firemen, polices, paramedics, military, and other crisis management organizations), operators in a crisis center room, and civilians (that are victims and witnesses). The users use the developed iconic interface on their PDA to report situations around their location. A distributed-system architecture based on a MANET connects the mobile devices. The MANET allows a peer-to-peer wireless network that transmits from PDA to PDA without the use of a central base station (access point). A blackboard structure is used for sharing and distributing information.

The remainder of this paper is structured as follows. The following section starts with related work. In section 3, we will concentrate on our developed visual language interface and the world knowledge formation based on user reports (visual language). Its testing environment is presented in section 4. We continue with describing our experiments in section 5. Finally, section 6 concludes this paper.

2. Related Work

Icons have already been used for the purpose of intercommunication in the Middle Ages, for instance for denoting systems of astrological signs. It could be argued that the hieroglyphs of ancient Egypt were used as an iconic communication language. Nowadays, we find ourselves surrounded by iconic communication ranging from device controls and icons used in traffic, to iconic communication systems assisting speech impairment. Typically, such icons are visually different across languages even if they are meant to stand for the same concept. Additionally, icons form an important part in most GUI-based computer applications as a small graphical representation of a program, resource, state, option or window.

Recent attempts have been done in developing computer-based iconic communication, for example: (a) the Hotel Booking System that allows communication on a restricted domain [29], (b) CD-Icon that was designed as pure person-to-person communication system [4], (c) Sanyog that was designed for disabled people in India [3] and (d) the Elephants memory that allows the user to build visual messages by combining symbols from a predefined vocabulary [19]. However, most of these systems are hard to learn or language specific. They are either based on too complex linguistic theories or on non-intuitive (or non-self-explanatory) icons. A thorough research has been done by Leemans [25] on the use of iconic language as a universal language. Visual Inter Language emphasized simplicity and ease of use. It has allowed people to still communicate with each other despite not sharing a common language.

Information about the use of symbols (or icons) in the field of crisis management was not readily available. Most symbols used were already available in GIS or graphic software that was used by agency or institutions. A comprehensive research on guidelines and standards for the design of hazard and emergency maps was performed by Dymon [13]. The research reviewed the use of existing symbols, including the standard map symbols of US military and NATO (APP-6a - [11]). The resulting symbols are claimed to be scalable and flexible across both discipline and cultural differences. Based on this research, standard map iconic symbols are promoted by the U.S. Government for emergency response applications on a national basis [17]. The symbols have been tested nationally, including participants from private and public sectors. They are used for sharing information during crucial emergency situations by emergency managers and people responding to disasters. This set of symbols is also used by the governments of Australia and New Zealand.

In the years after September 11, 2001, the attention is increasingly shifting toward cutting-edge technologies based on multi-sensor communications [16], 3D geospatial information [24][26], and (3D) visualization on mobile devices [23][35]. Information is the basis for decision-making, and it is essential in crisis situations. We aim at providing a communication interface for sharing information, while the decision-making process in using the information is not the focus of the paper. The need of emergency response systems that incorporate aspects of human observations has never been more apparent. The architecture of WHISPER [36] includes a web interface for emergency responders to share information during emergency response activities. The system provides a unified view of an emergency response activity based on the received information. Moreover, this architecture also integrates relevant data repository of all emergency services to support their decision making process. The RESCUE project [30], with their testbed CAMAS [31], allows users to send reports via a web interface using natural language messages. This system is able to parse and analyze users' input, classify crisis events and create situation awareness. The VCMC model is also using a web interface [33]. It allows its users to share data about crisis situations in real-time and to discuss information.

An iconic interface for reporting observations in a Mobile Ad-hoc Network (MANET) has been developed by Tatomir and Rothkrantz [40]. The system allows its users to share and merge topological maps in damaged buildings using observations from individuals present in an infrastructure-less network. Apart from representing crisis events like fire, explosion, etc, a set of icons is also used for constructing a map representing features such as crossing types and road blocks. The featured knowledge can be thus used for providing guidance to given locations, finding the nearest exit, coordinating rescue actions of individuals and groups, collecting information concerning crisis indicators, and reasoning about the state of the building.

Modeling and simulation plays an important role in testing a new technology in disaster setting, as pointed by Robinson and Brown [37]. An agent-based simulation, DRIFTS, was designed to model the information flow between agents involved in a crisis situation. The simulation models the influence of decisions and actions of an agent to other agents. It allows human users to modify the disaster data and agents' characteristics. In contrast, Loper and Presnell have developed an agent-based simulator that simulates information flow in the crisis center [28]. A few efforts have been directed toward integrating real life user interactions and simulations. For example, Jain and McLean integrated gaming and simulation systems for emergency response training [21]. DrillSim simulates real training activities that are integrated the actual instrumented sensors and communication infrastructure [2]. In assessing the usability of a user interface, a mixture of computer and live simulations is necessary. Therefore, we can capture the interaction between human users and the interface.

3. Visual Language Interface

Crisis management relies on teams of people who must collaboratively derive knowledge from geospatial information [17], that are usually presented via maps. Our developed user interface also provides an observation map to which users may attach visual symbols describing situations relevant to a particular location (see Fig. 1).

Symbols can be icons, geometrical features or icon strings. Geometrical shapes, such as arrows, lines, ellipses, rectangles and triangles, can be used for indicating a given area on the map. They can also be used for highlighting or emphasizing an object, an event or a location on the map. Each icon has several attributes which enable the user to provide additional information. For instance, the icon for "fire" has the attributes status, size and intensity (for example under control, big, high). The interface, however, is not limited to providing icons for the representation of atomic concepts such as fire, ambulance, victim, etc, but also caters for icon strings. The icon string can be formed using a dedicated pop up window where the intended information can be submitted.

Fig. 1. Icon-Map Application on PDA

For ensuring accurate and complete user reports, the interface provides menus for deleting and inspecting or altering the observation form, and menus offering map zoom and pan functionality. When user observations are submitted, the system processes the data, adapts its world model accordingly, and transmits the changes to the network.

3.1 Constructing Icon String

Fig. 2. The developed visual language interface

Our users can select a sequence of icons for communicating observations (see Fig. 2). Our developed visual language interface is able to interpret the sequence and convert it into natural language. The iconic sentence constructions are based on the notion of simplified speech by significantly reducing sentence complexity. Each constituent icon provides a portion of the semantics of the sentence it forms. The meaning of an icon string is derived from the combination of its constituent icons, and cannot be detected without evaluating the semantics of the sentence as a whole.

Experiments have been conducted to acquire knowledge on formulating iconic messages from sentences [14]. As comparisons, large number corpora were analyzed. Both studies had a similar result: each sentence is composed by a small number of icons representing important keywords. Based on these studies, we have developed grammar rules using Backus Naur Forms and English grammars. Several icon categories exist, such as nouns, pronouns, proper-nouns, verbs, adjectives, adverbs, prepositions, and quantifiers. For example, as can be seen in Fig. 3, the "building" icon belongs to the noun category. Icons are then combined into phrases of sentence categories such as: Sentence (S), Noun Phrase (NP), Prepositional Phrase (PP), etc.

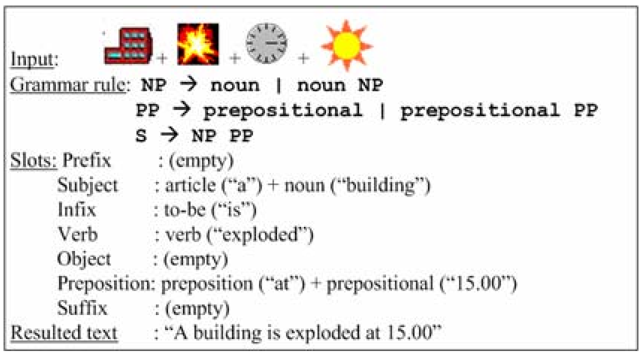

Fig. 3. An Example of an icon string input conversion

A parser checks the input against predefined grammars. If the input is syntactically correct, seven slots are created: prefix (for question words), subject, infix (for a to-be, an auxiliary and a negation), verb, object, preposition, and suffix slot (for a question mark, an exclamation mark or "please"). Slot position depends on the type of a sentence. For example, in the case of a question sentence, the infix slot may be located between the prefix and the subject slot.

After transforming the input into the slots (see Fig. 3), some additional rules are fired, which specify the conversion of the iconic sentence into a natural language sentence based on the semantic context of the former. Some examples are rules for changing words format: adding prepositional, question words, auxiliary verbs, a to-be, and articles. To develop these rules, we analyzed corpora that included different sentence formats. Following each input, the resulted natural language text is displayed and ready to be shared to others on the network.

3.2 Usable Interface

To facilitate communication, the interface provides a large vocabulary of icons. By three ways: (1) designing good icons; (2) designing a usable interface; and (3) providing a next icon prediction, our interface design concept supports users to create iconic messages using as small number of steps as possible.

To avoid poorly designed icons, we have followed some guidelines, for example [20][1]. Since this interpretation relation is a subjective matter, we have performed user tests for each icon in the context of other icons based on Horton's approach [18]. The test participants were selected to include different nationalities to solve problems of linguistics and culturally bias of the interpretation of an icon. If the interpretations of different viewers to an icon were not the same as the intended meaning of its designer, this means that the icon was required to be redesigned.

Our interface design concept provides icon navigation in three ways: (1) grouping related icons by concepts to hint users finding desired icons [18], (2) providing a distinctive appearance of a selected icon which contrasts it from the rest of the unselected ones, and (3) providing a real-time distinctive appearance by which icons can be selected according to syntactical rules.

We develop an icon prediction system by adapting an n-gram word prediction technique [42]. The probability of an icon string is estimated using Bayes rule:

$$P(s) = P(w_1, w_2, ..., w_n) = \prod_{i=1}^{n} P(w_i \mid w_1, ..., w_{i-1}) = \prod_{i=1}^{n} P(w_i \mid h_i)$$

where h_i is the relevant history when predicting w_i (*icon*$_i$). The prediction system operates by generating a list of suggestions for possible icons. A user either chooses one of the suggestions or continues entering icons until the intended arrangement of icons appears. Besides error prevention and improving input speed, the interface also offers the ability for users to concentrate their attention on other tasks than operating the application. Our developed visual language interface collects the data from user selections during interactions.

The results of any user interaction are provided as direct as possible as the users intended. Thereby, although some icons are still unknown, the users can learn them on trials.

3.3 World Knowledge Construction

By employing a common ontology, our developed system collects and processes all incoming iconic messages and builds an aggregated global world model. The world model consists of two contexts: the dynamic and the static. The dynamic context is represented by a chain of temporal specific events and a group of dynamic objects in action at a certain location in the world. While the static context is actually the geographical information concerning crisis location, such as building, street, and parcel. The knowledge of both contexts is stored in the system's ontology represented in W3C-OWL [43]. It has direct links to the visual symbols on the user interface.

Fig. 4 shows the taxonomy of the class WorldObject referring to an entity that is involved in a crisis event. The icons are the instances of the WorldObject's subclasses. For example, the icon "victim" is an Actor while "ambulance" is a means of Transportation.

```
WorldObject
  Static-Object
  Dynamic-Object
     Actor
     Event
     Transportation
     Tool
     Substrate
     Preposition
     Geometrical Features
```

Fig. 4. The WorldObject taxonomy

We represent geospatial knowledge of crisis situations using graphs for data modeling. The graph connects its nodes based on their approximated spatial coordinates in the world. The lower nodes represent objects, actions or events in the world. They not only contain specific information of events and objects, but also their current status (for example living condition and dynamic spatial state), their temporal information (for example frequency and time point), and their spatial information (for example current location, origin, destination and path). The arcs represent the hierarchy of groups of individuals or show the relations among concepts (for example result, cause and contain). At the root, a node describes the perspective location of the crisis event. The illustration in Fig. 5 shows some events: a collision of two transportation entities (car and truck), has resulted in an explosion, and the explosion has caused toxic gas and fire.

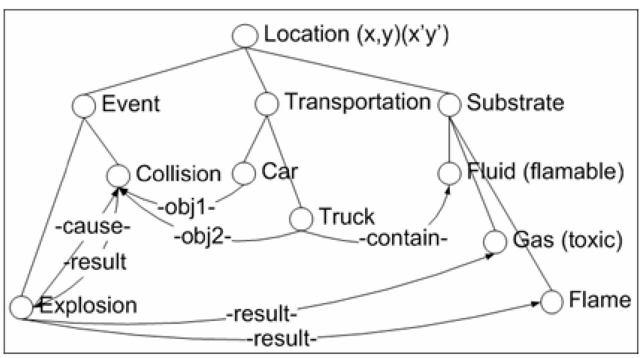

Fig. 5. Graph-based symbolic representation of a crisis event on a certain location

Fig. 6 shows communication flows using our developed interface. The *Local World Model Generation* extracts user inputs into symbolic representation by the use of the domain ontology. This symbolic representation is sent to the blackboard via a MANET. Finally, based on the new constructed global world model, the *Global World Model Decomposition* updates the user's display. Since the world model contains the spatial information of its objects and events in the world, this process is almost straightforward. The interface only checks whether the knowledge has been stored in the form of icon strings, otherwise it will be represented by icons on the map. If the interface finds any ambiguity, it will solve this by reasoning. For example: if the global world model contains the information "explosion={location=(x, y)(x', y')}", but a small number of users send the same report from a location somewhat close by, yet not exactly matching the above, the reasoning engine will select the above coordinates and update these users' display.

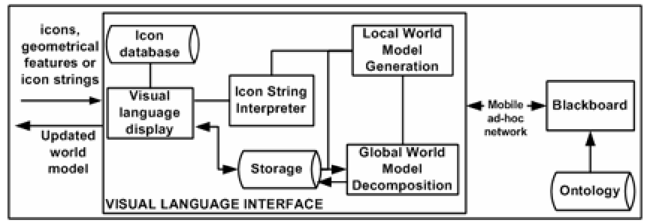

Fig. 6. Schematic architecture of the communication interface

4. MULTIAGENT DISASTER AND RESCUE SIMULATION

We used a simulation environment to facilitate the testing of the proposed interface [5]. The simulation offers integration with real life observations of a crisis situation using the developed iconic interface in a MANET. Human observers' reports of the physical world will be fed into the simulator to update and hence calibrate the activity in the disaster simulator. Fig. 7 shows a schematic view of the simulator. We represent the geospatial knowledge of the crisis simulation world using grids and waypoints for data modeling. Waypoints are vectors containing information about the environment directly surrounding a certain point on the world. They include information about the world's physical phenomena (for example current outdoor temperature, wind speed and direction) and observer reports (for example "smells gas odor" and "hears an explosion"). This representation is simplistic yet rich enough for capturing a variety of situations.

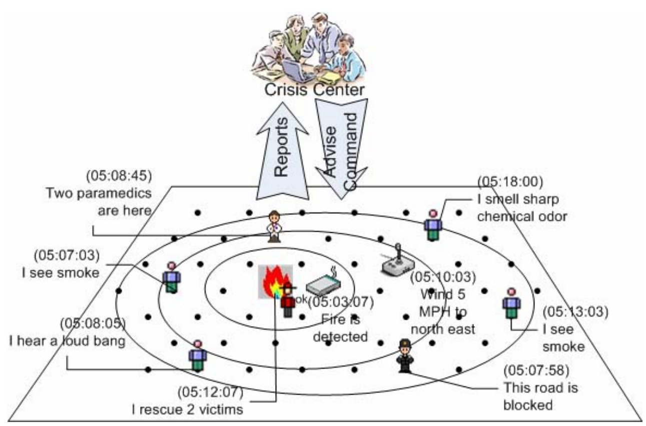

Fig. 7. Overview of multiagent disaster and rescue simulator. Disaster dispersion (represented by ellipses) occurs on the world with waypoints (dots). Agents in the field report their observation

An agent in the field is an autonomous participant that drives the crisis simulation by reporting observations. It can be a human, a virtual actor or a virtual sensor device (for example a smoke detector and a wind meter). At any given time, agents are associated with a given location in the geographical space, i.e. the location at which the disaster is played out.

The Crisis Center will collect the reports to form a global world model about the reported crisis events. It has an expert system to give the most probable causes and advice about the current situation based on the world model. For example if an explosion report comes in and the current temperature is high, the chances of fire increased, firemen are sent and evacuation may be deemed necessary.

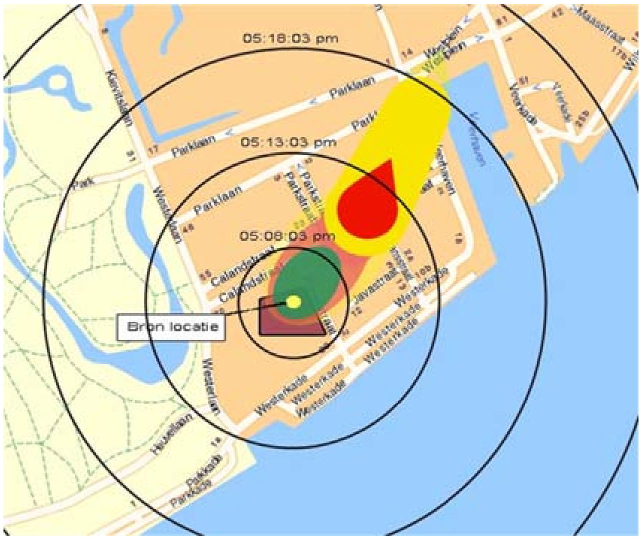

Fig. 8. An example of gas dispersion scenario shown by the simulator's interface

Our developed crisis simulator models physical phenomena such as spreading fire, gas dispersion and spread of a hazardous material. It represents at any time and for each location, the impact of the crisis to other entities (for example the intensity of fire, gas pressure, etc) based on the information stored in the waypoints. Fig. 8 shows an example of resulted gas dispersion after 11 minutes.

Events of a crisis simulation are generated based on a script scenario. The scenario is a set of snapshots taken at every time unit. Each snapshot contains a multitude of waypoints of a grid cell. It is executed in a minute by minute basis. The current implementation is able to simulate toxic gas dispersion and spreading fire scenarios. In order to capture real actors in the virtual space, the simulator is utilized by a sensing infrastructure that monitors and extracts information from real actors needed by the simulator, for example agent's location. Likewise, to enable a real-actor to participate in a simulated reality, we provide him/her with knowledge of the virtual world. In our test scenario, our real actors are moving dynamically using their mobile device to report events. Therefore the current version of the simulator is able to display an image of a situation relevant to the current scenario based on the location of an agent.

5. EXPERIMENT

A set of experiments has been conducted to assess whether or not users were able to express their concepts or ideas using the provided icons and to address interface usability. Eight people took part in the test and played the role of a human observer, while the crisis center was performed by the simulator. The participants were selected in the range age of 25-50 years old. For these experiments, their demographics information was considered not relevant. The simulation provides a methodology for modeling the dynamic nature of disasters. Thereby, we expected to be able to capture the dynamic creations of messages.

Table 1: First minutes of example scenario based on Fig. 7

Generated event	***Possible action***
05:03 Fire at area (x,y)(x',y') A fire detector detects fire and activates alarm	*Human observers*: see fire and report it to the crisis center *Crisis center*: receive reports and send a call to Fireman for checking
05:07 Fire and smoke develop A thermometer measures the current temperature Firemen are on their way to (x,y)(x',y')	*Human observers*: report to the crisis center about developed smoke and the present of firemen *Crisis center*: receive reports, send policemen to (x,y)(x',y')
05:08 Explosion Policemen block roads in the danger area	*Human observers*: report to the crisis center about damage and casualties, a loud bang and the present of policemen *Crisis center*: order extra units firemen and paramedics to (x,y)(x',y')
05:10 Professionals in action A wind meter measures the wind speed and direction Paramedics arrive at (x,y)(x',y'). Firemen start extinguishing fire and rescuing victims, paramedics help victims and policemen guard the area	*Human observers*: report to the crisis center about the professionals' activities *Crisis center*: send advise to the professionals and civilians
…	…

The tasks were created based on a scenario that was fed into the simulator. They were designed in such a way to give our participants freedom to answer. The simulator used images of real crisis situations. Based on generated events in the scenario, these images were sent to the participants based on their location in the world. The participants were asked to report what they saw or might sense using the visual language interface on their PDA. Table 1 shows some examples of generated events in a scenario. For each event, the table also shows (expected) possible actions of our test participants (human observers) and the crisis center. (Fig. 9(a)) shows two examples of images that were sent to the participants at 05:10 (professionals in action). After the experiments, we interviewed their satisfaction. All activities were recorded and logged to be analyzed afterward.

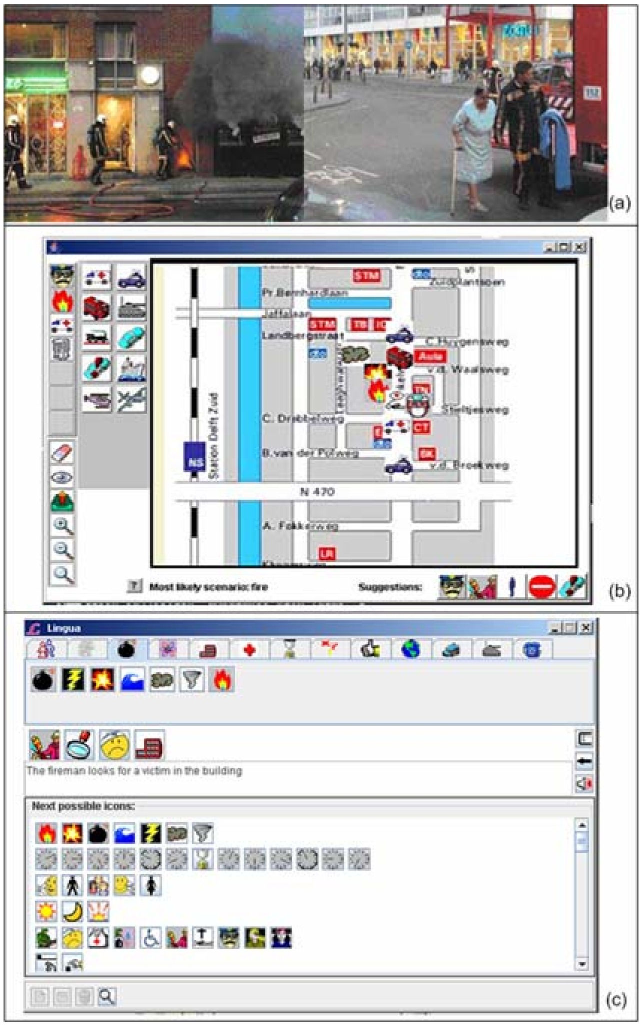

Fig. 9. Evaluation data: (a) two examples of photographs of a real crisis situation, (b) an example of visual language messages sent by a user on a map, and (c) an example of an icon string created by a user

Smith's measurement of the sense of being lost in hypermedia [39] was adapted to measure disorientation of being lost in a visual language interface since our icon space was made up of interlinked icons. Our initial hypothesis was that a visual language interface might give cognitive overload and disorientation to its users. For a perfect search, the lostness rating should have been equal to 0.

Fig. 9 shows an example of user interaction with the developed interface. The experimental results showed that our target users were capable of expressing the concepts and ideas in their minds. The users accomplished their tasks with relevant iconic messages. However, some users had problems finding the right icon for certain concepts in their minds. This was indicated by the high number of the lostness rating of five sequence messages (Fig. 10). This was in some cases due to the fact that they did not recognize some of the icons on the user interface. In other cases, it was due to the limited number of icons provided. It appeared that the test users tended to keep searching the icon they intended. This slowed down the interaction. The time was needed to find the most relevant concept to represent their message. The participants should have rethought other concepts that could fit with the problem domain. This usually occurred when our participants tried to familiarize the interface. Future work is necessary for analyzing more corpora and icons that are relevant for crisis situations. Apart from these problems, we viewed decreasing lostness rating in terms of improvement of user performances. Our test users had taken benefits provided by the interface, for example visual cues and the next icon prediction tool, in creating iconic messages. We also concluded that our test users only needed a small period of time to adapt to the developed visual language interface.

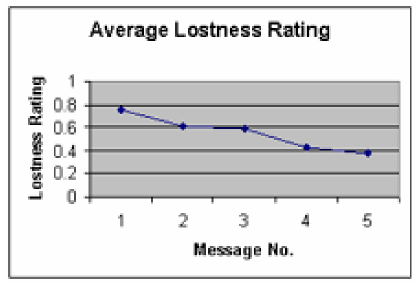

Fig. 10. Average lostness rating for five sequence messages during experiments

6. Summary and Conclusion

In crisis situations, many different parties are involved in the crisis management. Communication between these parties is important and is traditionally handled using precompiled scripts or handled in an ad-hoc fashion. A comprehensive experimental system for maintaining reliable communication in crisis events has been developed. It consists of the use of a visual language interface on a PDA for reporting situations in a MANET-based communication. The developed interface allows users to describe a situation using the combination of icons, geometrical features and icon-strings on map-based interfaces.

Natural language processing has provided a method for interpreting and converting iconic messages. To solve the problems of ambiguity and missing information that resulted by this type of messages, we have approached it by designing usable icons and the use of rules. Using the graph for the modeling of the observers' world knowledge, we can represent the topographical data of the crisis event. By employing common domain ontology, the world knowledge is able to share a common semantic representation of the reports from users. By collating information from all users, these reports can be filtered to form unambiguous and complete information, using one to complement and enhance another.

There are many guidelines and standards for designing icons and interfaces for mobile devices. We used semiotic approach, in particular, for designing language and culture independent icons. We have followed the guidelines during the design and development process. To support fast interaction, the developed interface provides a next icon prediction tool. Our test participants found that our tested iconic interface has met their expectations. These users needed a small period time to learn the interface.

We tested our proof of concept on a serious game environment of a disaster and rescue simulator. The simulator allows the dynamic creation of scenarios and determines the ability to adapt to a changing disaster landscape. We were able to capture the interactions between people and the developed interface in a scenario. The experimental results showed that the visual language interface offers a usable communication tool to investigate. Our test users were capable of reporting situations using arrangements of visual symbols for the given situations. However, we also found that users generated some arrangement of icons, which were out of domain. Besides adaptation time is required, this may indicate that better icon designs and more icon vocabularies are necessary. Furthermore, more experiments in real crisis situations are necessary for determining the performance of the system in real life situations.

Visual language has already been a survival communication method for human beings, especially when verbal communication is not feasible. The proposed communication paradigm is not meant for replacing any primary communication, i.e. speech, but to open up new possibilities for obtaining information about the crisis. The use of icons to represent concepts or ideas makes user interactions on the developed interface particularly suitable across user diversity in language-independent contexts. Of course, this comes at a cost of having to process all this information and use it in a sensible way. Multiple inputs have to be analyzed and fused to determine the context of the crisis. Based on this context, proper decisions need to be made, and communicated to the parties involved. Future work has to be done to facilitate communication between different parties by providing this functionality. Such a system is necessarily multimodal since it must accommodate people working and coordinating collaboratively resolving crisis in non-deterministic environments. It should be designed to permit switching among modes to take advantage of the modality best suited for a task and environment. Therefore, human users can use all modality channels simultaneously, using one to complement and enhance another.

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