# KNOWLEDGE-ORIENTED SENSOR WEB FOR DISASTER MANAGEMENT: FROM SENSING TO DECISION MAKING

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**ABSTRACT:**

The shocking consequences of disasters and natural hazards have already proven the urgency and necessity of disaster management and emergency response. Timely and updated information reflecting the newest disaster situation is extremely important for effective emergency response and efficient actions. While significant research has been demonstrated on the current research of disaster management, the problem of how to offer timely, even real time data and information to disaster managers and emergency responders is still far from solution. The emergence of sensor web does provide a promising way to solve this problem. However, most of current sensor web researches are mainly focused on data collection, sensing and real time monitoring of the disaster targeted, little research has been done on the process of decision making during disaster management and emergency responses. Especially, for improving the strategies of disaster management, in the context of sensor web, the inherent relationship between sensing and decision making really needs to be explored deeply. For an operationally effective disaster management, its sensing, monitoring, detection and decision making must be integrated seamlessly. In order to tackle with the limitations above, this paper presents a conceptual framework of knowledge-oriented sensor web for disaster management. Through the proposed architecture, disaster sensing and disaster decision making can be integrated closely by using multi-agent system and rule-based expert system. Thus, the existing sensor web can be potentially extended and greatly enhanced from mere disaster sensing and monitoring to a higher level, i.e., knowledge-oriented decision making, which will better support disaster management and emergency response.

## 1. INTRODUCTION

Disasters and hazards are absolutely unavoidable, though a great amount of efforts have been made in the domain of disaster management and emergence response (Kwan and Lee, 2005; McQuaid, 2006; Napier, 2003). Every year, all kinds of disasters and hazards definitely bring great damage and huge loss to human lives and properties. No matter they are either nature hazards or man-made disasters (such as terrorism). The shocked aftermath of each hazard has already proven the urgency and necessity of disaster management. Timely and updated disaster information is extremely important for effective emergency response and efficient actions. Timely disaster data and information will absolutely help disaster managers make better decisions and take actions in time. Unfortunately, for current existing disaster management, though significant research and interesting results have been demonstrated, the problem of how to offer timely, even real time data and information to disaster managers and emergency responders, is still far from solution (Erharuyi and Fairbairn, 2003; Fiorucci et al., 2005).

With the rapid development of sensors technology, the emergence of sensor web does provide a promising way to solve this problem. Although the current research of sensor web is still at its early stage, the practical deployment and applications of sensor web have already shown its great potential (Delin, 2004; Gibbons et al., 2003; Liang et al., 2005; Paul, 2001). A certain fact is that more and more attentions have been paid into the research of sensor web (McCarthy et al., 2008).

It has been known that, for an operationally effective disaster management, sensing, monitoring and decision-making should be integrated seamlessly. However, most of current sensor web researches are mainly focused on data collection, real time sensing and monitoring of the disasters targeted, little research has been done on the process of decision making during disaster management and emergency responses. Especially, for improving the strategies of disaster management, in the context of sensor web, the inherent relationship between sensing and decision making really needs to be explored deeply. The reason of above limitations lies in the following facts: 1) the research of sensor web is still at its infancy stage, 2) disaster decision making involves complex relationships and interactions among a variety of disaster response entities. These entities include human and organizations, each of them owns a heterogeneous role in support of disaster management. For the research of disaster decision support, there are two fundamental questions need to be answered. The first question is how to represent disaster response entities and the interactions among them. The second question is how to capture and represent the expertise and professional knowledge owned by those entities.

In order to answer above questions, in the paper, a conceptual framework of knowledge-oriented sensor web for disaster management is proposed and discussed. For representing heterogeneous disaster response entities and their interactions,

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multi-agent system is introduced. Each entity can be represented as a corresponding agent through multi-agent system. Multi-agent system is adopted to model the behaviours of each entity, especially the collation and cooperation of all relevant entities during disaster management. For capturing and representing each entity's expertise and professional knowledge, rule-based expert system is introduced. By using rule-based expert system, the expertise and knowledge of each entity can be represented as a set of rules and captured into disaster management knowledge base. Through the proposed architecture, disaster sensing and decision making can be integrated closely. Thus, the existing sensor web can be potentially extended and greatly enhanced from mere disaster sensing and monitoring to a higher level, i.e., knowledge-oriented decision making, which will better support disaster management and emergency response.

The rest of this paper is organized as follows. The following section presents an overview on current research of sensor web. Then, Section 3 discusses multi-agent system, rule-based expert system and their potentials to disaster decision support. In Section 4, a conceptual framework of knowledge-oriented sensor web for disaster management is proposed. Finally, a summary is provided and future study is discussed.

## 2. SENSOR WEB: A NOVEL SENSING APPROACH

Sensor web is attracting more and more research attentions. Many organizations and universities step in the study of sensor web (Chu et al., 2006; Delin, 2006; Liang et al., 2005; McCarthy et al., 2008). Until now, there is no a universal definition of sensor web which can be accepted without any disagreement. A variety of definitions are also proposed by different researchers (Delin et al., 2005; Liang et al., 2005), all these definitions substantially help clarify the research boundary and goals of sensor web, though the focus of each definition are definitely different. No matter how to define a sensor web, a well accepted fact is that for any proposed definition, the basic features of sensor web should be inclusive. The paper attempts to summarize the basic features of sensor web instead of proposing a definition.

### 2.1 The Basic Features of Sensor Web

Sensor web has the following basic features: sensing, autonomy, dynamic reconfiguration, standards-based interaction, access.

- Sensing: for a sensor web, one of its fundamental features is the sensing ability
- Autonomy: if a sensor web is autonomous, it means that the sensor web can operate without external intervention.
- Dynamic reconfiguration: it refers to the dynamic configuration ability of sensor web based on the changing state and monitoring goals.
- Standards-based interaction: All components or elements within sensor web can interaction through standard service, such as OGC web service.
- Access: Sensor web must provides a mechanism to support the accessibility of sensing data or coordinated measurements.

### 2.2 OGC Standard: Sensor Web Enablement (SWE)

Within a sensor web, there are all kinds of working sensors. Moreover, the sensors are heterogeneous. In order to achieve a common sensing and monitoring goal through sensor web, obviously, all the sensors involved should be able to exchange data and information smoothly. It means that data interoperability is critical for sensor web. More importantly, from the users' perspective, the discovering and accessing of sensing data must be standardized so that the exchange of sensor web services becomes possible. Unfortunately, the lack of data interoperability heavily hinders the practical application of sensor web. In order to solve this problem, Open Geospatial Consortium (OGC), a widely accepted organization, which focuses on the development of open standards for geospatial services, proposes a geospatial standard, i.e., Sensor Web Enablement (SWE) (Chu et al., 2006; Reed et al., 2007). SWE enables the implementation of interoperable and scalable sensor web. Just like the using of Hyper Text Markup Language (HTML) and Hyper Text Transfer Protocol (HTTP) turns the exchange of information on the internet into reality, SWE makes the discovery and exchange of sensor observations possible and feasible. In fact, SWE has become a de facto standard for the development of sensor web. Table 1 summarizes the details on SWE.

| | Specification | Description |
|---|---|---|
| Standard Models and XML Schema | Observations & Measurements Schema (O&M) | Encoding observations and measurements |
| | Sensor Model Language (Sensor ML) | Describing sensors |
| | Transducer Markup Language (TransducerML or TML) | Describing transducers |
| Standard Web Service Interface | Sensor Observations Service (SOS) | Requesting and retrieving observations |
| | Sensor Planning Service (SPS) | Requesting user-driven acquisitions |
| | Sensor Alert Service (SAS) | Publishing and subscribing to alerts from sensors |
| | Web Notification Service (WNS) | Delivering messages or alerts asynchronously from SAS, SPS or other web services. |

Table 1. OGC SWE Specifications

### 2.3 Service Oriented Architecture and Web Service

Service Oriented Architecture (SOA) is an essential infrastructure which can support the integration of distributed heterogeneous systems. SOA splits functions into distinct units, i.e., services, which are distributed over a network. The services can be published, discovered and requested dynamically within the network. The communication of different services is achieved by using XML messaging mechanism. Through SOA, these distributed services can be united and reused to support the new applications (Bell, 2008). Figure 1 gives an illustration of SOA.

Web service can be used to support the implementation of SOA. Web services are independent from platforms and programming languages. Moreover, they are accessible over standard internet protocol (Ericsson, 2007).

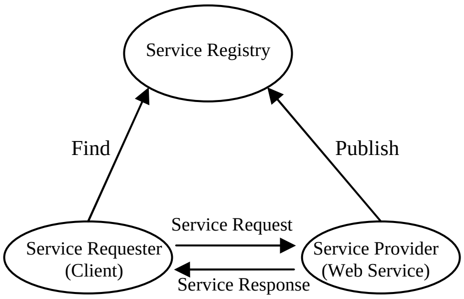


Figure 1. Illustration of Service Oriented Architecture (SOA)

## 3. DECISION SUPPORT SYSTEM FOR DISASTER MANAGEMENT

Disaster management is a very complex process. It contains not only sensing, monitoring and detection of pre-disaster, but also response, rescue and recovery of post-disaster. That is to say, disaster management covers all four stages including preparedness, mitigation, response and recovery (Chen et al., 2006; Fiedrich and Burghardt, 2007).

As stated above, disaster management involves a variety of disaster response entities, such as ambulance team, fire brigade, doctors and police office, etc. On the one hand, each entity has its own duty and responsibility. On the other hand, all the entities involved must cooperate and collaborate closely. It means that their interactions must be considered carefully. Multi-agent system and rule-based expert system play critical roles in the implementation of decision support for disaster management. More details will be discussed in the following section.

### 3.1 Multi-Agent System (MAS)

Multi-agent system provides a mechanism and platform to support the cooperation and collaboration among agents. Within a multi-agent system, the task is split into individual subtask. Each agent will take charge of one specific subtask. Finally, the task can be achieved through the cooperation and collaboration among agents. Thus the very nature of multi-agent system does fit the requirements of disaster management. In the context of disaster management, each disaster response entity can be regarded as an agent, and then each agent can be assigned to a subtask. Therefore, the process of disaster decision making can be transformed into the cooperation and collaboration of corresponding agents. The representation of disaster response entities through multi-agent system is shown in Figure .

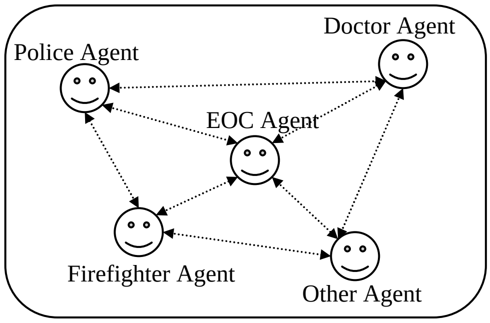


Figure 2. Representation of Relevant Entities using MAS

### 3.2 Rule-Based Expert System

Rule-based expert system provides a nature way to capture and represent the expertise and professional knowledge related with disaster management and emergency response. Within a rule-based expert system, domain knowledge will be represented as a set of rules. A rule presents specific description of how to solve a given problem. Each rule includes the IF…THEN structure, i.e., IF <condition> THEN <action>. When the condition of IF part comes into true, the rule is said to fire and then the action of THEN part will be executed. The basic workflow of a rule-based expert system is shown in Figure 3.

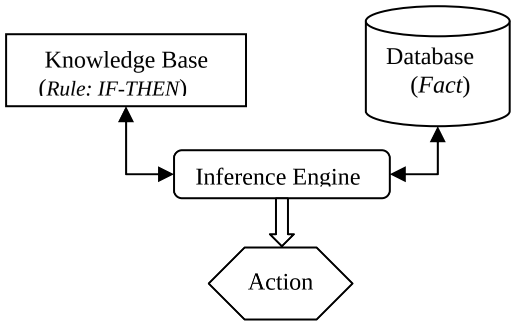


Figure 3. Basic Workflow of Rule-Based Expert System

When using rule-based expert system, a fundamental question is: where does the domain knowledge come from and how to capture them into knowledge base?

For disaster management and emergency response, the source of relevant knowledge includes human expertise and documented data and information. The knowledge obtained from human experts and documented data and information can be captured into knowledge base through knowledge engineering. Figure 3 shows the process of creation of disaster management knowledge base.

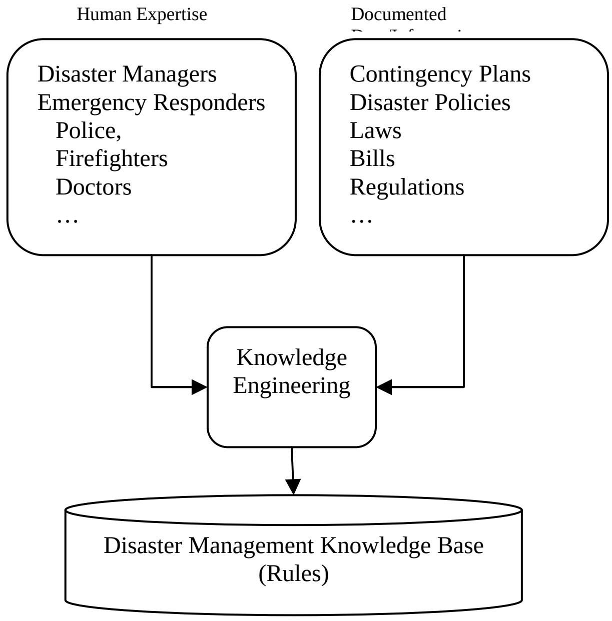


Figure 3. Creation of Disaster Management Knowledge Base

## 4. KNOWLEDGE-ORIENTED SENSOR WEB

Current research of sensor web is primarily focused on the sensing and data collection. Specific to the domain of disaster management, most of applications only use sensor web as a sensing tool to collect disaster monitoring data and detect disaster events. In fact, as a complete cycle of disaster management and emergency response, sensing, monitoring and detection are only parts of it. Response, countermeasures and actions taken by disaster managers and emergency responders play same critical roles for the success of disaster management. In order to meet this need, in the following section, a conceptual framework of knowledge-oriented sensor web for disaster management is proposed.

### 4.1 Knowledge-Oriented Sensor Web: Conceptual Framework

The aim of proposed framework (Figure 4. ) is to integrate disaster sensing with disaster decision making, thus existing sensing-based sensor web can be enhanced and upgraded into knowledge-oriented sensor web.

The following abbreviations are used in Figure 4.

P: Prediction
ED: Event Detection
DRA: Disaster Response Agents
SA: Sensor Agents
SP: Sensors Platform
SM: Science Models
R&R: Retasking & Reconfiguration
A&R: Actions & Responses
D&H: Disaster & Hazard

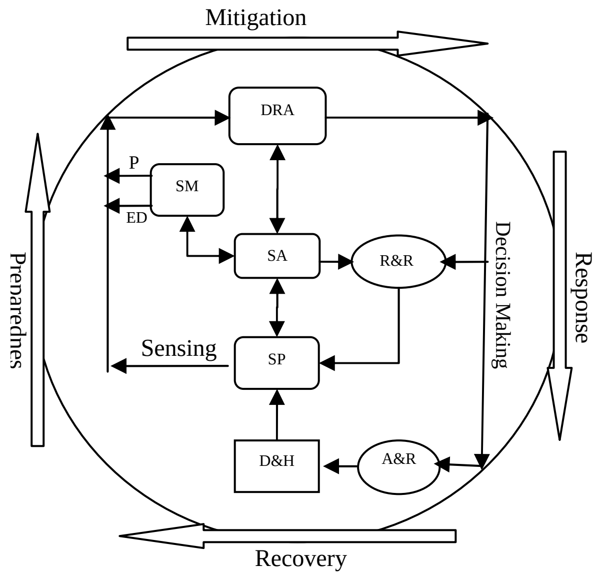


Figure 4. Conceptual Framework of Knowledge-Oriented Sensor Web for Disaster Management

### 4.2 Interactions between DRA and SA

When implementing a knowledge-oriented sensor web for disaster management based on the proposed conceptual framework, the most important aspect of this kind of sensor web is the interactions between disaster response agents (DRA) and sensor agents (SA). Without the implementation of the interactions between them, a knowledge-oriented sensor web for disaster management cannot be truly achieved. The details of interactions between DRA and SA are shown in Figures 5.

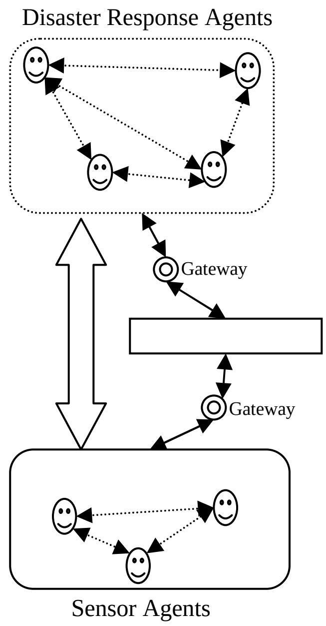


Figure 5. Interactions between DRA and SA

The interactions between DRA and SA lay a solid foundation for the implementation of knowledge-oriented sensor web. In fact, from the technical perspective, the interactions between them depend on the specific network environment. When operating through proprietary network such as wireless sensor network, the interactions can be carried out directly using specific communication protocol. However, when working through World Wide Web, i.e., Internet, a gateway must be needed to support the interactions between agent activities and standard web services such as OGC SWE compliant web services. A specific middleware can be developed to implement the gateway (Figure 6).

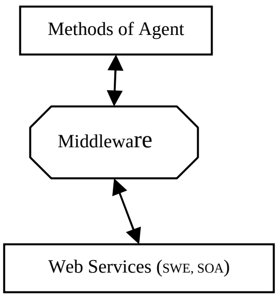


Figure 6. Gateway Connecting Agent and Web Service

## 5. CONCLUSION AND FUTURE STUDIES

For effective and efficient disaster management and emergency response, sensing, monitoring and decision making cannot be taken apart separately. The proposed framework does help to reach this goal. It not only offers real time disaster sensing and monitoring, but also provides real time dynamic decision making based on the sensing data. More importantly, it supports tight integration of both. Thus, with the adoption of multi-agent system and rule-based expert system into the framework, a knowledge-oriented sensor web for disaster management becomes really reasonable, operationally desirable and technically feasible. In the future study, two technical challenges must be further explored: 1) How to utilize knowledge engineering to capture expertise and professional knowledge into disaster management knowledge based, 2) How to develop a middleware to implement the gateway, which supports the interactions between agents and web services.

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