The AROUND project: Adapting robotic disaster response to developing countries

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Abstract — The global climate change induces an increase, in terms of frequency and devastating power, of natural disasters (particularly in developing countries). For facing this, there is a growing need for robotic assistance, for collecting information, managing disaster situation, rescuing victims and preserve human lives. It is one of the means recommended by the UNPD (United Nations Program for Development), which consist in the deployment of on-field automated monitoring, surveillance and reconnaissance systems. This paper outlines the research performed in the AROUND (Autonomous Robots for Observation of Urban Networks after Disasters) project. This project addresses the issue of developing a search and rescue multi-robot systems taking into account specific constraints of developing countries.

Keywords: *Disaster response, Multi-Robot Systems, Cheap robotics, Spatial Decision Support System, Robustness, Image retrieval.*

I. Introduction

The global climate is changing, affecting the planet with more and more frequent and devastating natural disasters. With growing confidence, scientists predict an increase in extreme weather affecting people worldwide, especially in developing countries. Vietnam, the target country for the project described in this paper, is considered as one of the most disaster-prone countries [7]. In addition, the fast pace of industrialization and urbanization shapes disaster risks through a complex association of concentrated populations and higher industrial hazards. As a consequence, in cities like Hanoi, not only are disasters (floods, storms, cyclones, fires, earthquakes, transportation and industrial accidents, or incidents stemming from hazardous substances) much more likely to happen, but these two uncontrolled dynamics make any intervention more difficult (like during the 1983 Hanoi earthquake [12]).

Reports on urban emergency relief [19] point out that the most serious difficulty is the delay of communication of reliable information between the authorities in charge, especially district authorities, which are supposed to coordinate efforts in real-time and make requests for support at the city level. Moreover, in Vietnam, the observation tools at their disposal are still rudimentary, with low level of automatization. The collection and transmission of data are mostly done manually [21], which results in delays between the occurrence of an event, its assessment and its handling.

One of the means recommended by the UNPD[1] consists in the deployment of on-field automated monitoring, surveillance and reconnaissance systems. The development of such systems is viewed as one of the keys for reducing the human cost associated with disasters, especially in urban areas, where most of the victims die during the first 48 hours partly because they are not detected on time [19] and where rescuers themselves face great dangers when exploring the impacted sites. The World Conference on Disaster Reduction (WCDR) [20] stresses this necessity in points no 89 ("Advanced technologies for disaster reduction") and no 90 ("Monitoring and modeling techniques for local communities and decision makers") of its final report. As a consequence, a number of researches worldwide ([13], [8]) already explore automated data collection and interpretation after disasters. However, most of them (conducted in developed countries) do not consider the economical and industrial constraints under which these systems could be deployed in developing countries, which are (and probably will remain in the future) the most affected areas. As a consequence, the results of these researches are hardly ever adapted to the economical constraints and climatic context of the concerned countries.

The aim of this paper is to outline both the specificities of developing countries in terms of "search and rescue" robotics and the AROUND[2] project. This project aims at providing robotic solutions under developing country constraints. Our paper is organized as follows: in Section II, we highlight the necessity to adapt "search and rescue" research programs in order to take into account context specificities of developing countries. Section III gives a global presentation of the AROUND project. In Section IV, we describe in details some

[1] United Nations Program for Development
[2] Autonomous Robots for Observation of Urban Network after Disaster

robotic challenges that we address in this project. We present in Section V prospects of our works and the first conclusions that we can draw.

II. Adapting robotic disaster response to developing countries

In the article introducing the RoboCup Rescue [8], the authors have proposed a new research stream aiming at using robotics for people search and rescue after a natural disaster. Actually the framework proposed in the RoboCup Rescue is very generic and we argue that it should be adapted to take into account specific constraints of developing countries. Taking particular interest in developing countries for rescue robotics appears really important because these countries are also the most disaster-prone [5].

We can identify three major issues that must be faced during the conception and deployment of a robotic rescue program in a developing country:

- **The cost of rescue robotic solutions.** A high cost is not compatible with the standard of living and the economy of these countries. To have at disposal robots up-to-date in terms of mobility, but also in terms of miniaturized and high-performance sensors is not possible in countries where the average revenue is about few hundreds dollars per month. The set of subsystems in a rescue robotic solution should be adapted to these financial limitations: mobility, communication, control, sensors, power…For example, sensors should be low-costs (opposite to lasers or sonars) and multi-services: they have to be used on the one hand to measure distances and on the other hand to shoot and gather disaster pictures necessary for the decision-making process. A way to face this constraint is to deploy cheap, modular and robust robots with decentralized autonomy and reliable communications skills.
- **An uncontrolled urbanization.** Developing country cities are evolving much faster than developed country ones. This entails an increase of the number of victims at the time of a natural disaster (because of low-quality building materials, failure to comply with security rules…) and this does not allow rescue teams to have reliable and up-to-date information about ground areas that have suffered damages, particularly in areas that are high-risk for rescue teams. Thus it is often necessary to gather information after a disaster and to have adequate tools for the damage identification.
- **The lack of logistic and infrastructural capacity** to respond effectively to disasters. This issue matches with a lack of preparation for providing adequate response to a disaster and with a lack of skilled staff for driving rescue operations. To overcome this issue, awareness and formation to rescue campaigns could be implemented for inhabitants (*i.e.* participatory approaches). This involves the development of specific tools able to collect information during a disaster and to display it clearly and synthetically. These tools should also be able to acquire domain knowledge from crisis management experts, particularly because these experts will perhaps not be available when a disaster occurs.

We can cite the following extra challenges that are still to be considered in future work: the robot maintenance in developing countries is very hard because of difficult climatic conditions and lack of skills to repair robots, the impact of robotic system deployment in a population that could not be well prepared… All these issues are actually extra constraints that should be added to the already difficult and highly constrained domain of robot deployment in the USAR (Urban Search And Rescue) context.

Above issues lead us to propose the project described in the following section which aims at developing solutions for challenges described in Section IV concerning communication, robustness and perception.

III. AROUND project description

The AROUND (Autonomous Robots for Observation of Urban Network after Disaster) project launched by several French[3] and Vietnamese partners [4] aims at addressing concerns expressed in the previous section by designing an automated observation system depicted in Fig 1 based on: (i) a local level with the deployment of autonomous mobile robots able to collect information in impacted urban sites and to dynamically maintain the communication links between rescuers, (ii) a global level based on a Spatial Decision Support System (SDSS).

While each of these levels of decision and action can be designed to be used separately, we claim that combining them into one unifies an integrated chain of command that can be adapted to different disasters is, besides the technical aspects found in the proposal, one of the innovations we introduce within this project.

In AROUND project, we are mostly interested by earthquakes in the city of Hanoi (Vietnam). Vietnam suffered two major earthquakes in the 20th Century, both in what is now Dien Bien Phu province. The first earthquake was in 1935 with magnitude 6.8 and the second in 1983 with magnitude 6.7. The two quakes caused cracks in the walls of houses in Hanoi, some 470 kilometers away.

The originality of AROUND compared to similar projects (like RoboCup Rescue) is that it takes the technological constraints of a developing country into account for designing the robots and intends developing researches to respect these constraints. This is in line with point no 93 of the WCDR ("To encourage the use of technology for disaster reduction in developing countries and for disaster-affected communities"), and, to make sure the technological transfer will be substantial, our project includes two partners from Vietnam already engaged in this kind of research.

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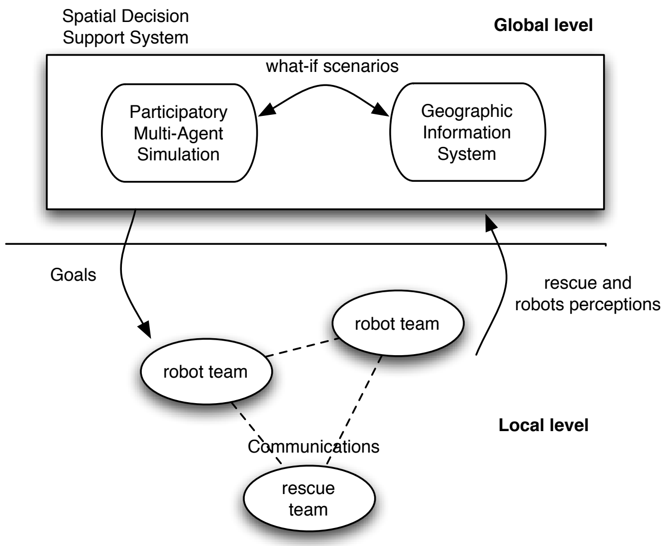

Fig. 1. Functional architecture of the AROUND project

A. *Deployment of cheap autonomous mobile robots*

The robots used in the AROUND project are robust and cheap[5]. The robots are connected with each other and with a decision centre by using a Wi-Fi wireless network. In contrary to Robocup Rescue robots, the robots used in the AROUND project are mainly dedicated to observation tasks. Indeed, their task is to get information in real time concerning the ground state. For cost reason, we propose to use video cameras as sensors for the robots. Thus, the video cameras will be used to get information concerning the localization of robots in the environment, to collect images allowing to evaluate the disaster status, and to recognize objects in the environment (*cf.* Section IV).

One can note today a broad movement of development of "low-tech" or "low-cost" (at design-time or during life-time) approaches for the design of technological systems: it is not only a question of reducing the costs by selecting less expensive or simpler components to adapt to economical constraints, but more generally to fall under the terms of sustainable technologies. We are following a similar trend in the AROUND project in order to produce low-cost reconnaissance robots adapted to emergent countries. Another interest of the use of low-cost technologies is that it will be easier to make technology transfers, to develop training programs[4] (like V-Unit and TechBridgeWorld held by the Carnegie Mellon Robotics Institute) and finally to support the emerging robotic industry in Vietnam.

B. *Spatial Decision Support System*

An important part of the AROUND project concerns the use of data collected by robots. Indeed, the goal of the project is to help decision makers to face natural disaster emergency. In this context, we propose to build a SDSS (Spatial Decision Support System) to support resources allocation and planning.SDSS are designed to provide the essential information needed by decision makers when those decisions involve location. For example, an SDSS might be used to design evacuation routes, select optimum locations for response teams, or dispatch evacuees to shelters. SDSS are specialised GIS (Geographic information system) that allow decision makers to get a better awareness of the impact of their decisions. As a GIS, SDSS allow to view, understand, question, interpret, and visualize spatial data such as the ones collected by robots. In addition, SDSS provide tools allowing to perform complex functions involving comparisons between several possible alternatives. Thus, we propose to integrate, in the SDSS, simulation capacities allowing the user testing different decisions and predicting their possible outcomes. Ensuring the pertinence of the predicted outcomes requires incorporating in the system the knowledge used in situation by responders. Unfortunately, this knowledge is not always well formalized in the response procedures. An approach to face this difficulty consists in using participatory methods. Indeed, agent-based participatory simulations are multi-agent simulations where human participants control some of the agents [6]. The goal is to extract information about their behaviour through their participation in the simulation. In the AROUND project context, the use of agent-based participatory simulations has two objectives. Firstly, augmented experiments allow the data (collected in real-time by robots) being integrated to participatory simulation. In fact, the simulation have some agents playing the role of robots in the aim of collecting real-time data about damages (on human life and property). These data will be interpreted and processed by rescue agents. Secondly, the "collecting data" behaviors of robots (for example: exploring environment, coordinating) can be viewed and improved by human actors through participatory methods (by letting human actors play the role of a robot agent and by learning his behaviour). Concerning this second point, we proposed in [3], an approach based on participatory methods aiming at learning the behaviour of human experts. In this work, a human expert observes the behaviour of an agent and has the possibility to correct it if this one is not pertinent. The agent takes into account this intervention to refine its behaviour. New scenarios are proposed to the human expert until finding one that is satisfied by the agent behaviour. We carried out an experiment concerning the learning of ambulance driver behaviour that shows promising results.

IV. CHALLENGING ROBOTIC ISSUES

As stated in Section II, developing countries have specific requirements because of their urban organization, their wealth and their technological skills. State of the art robots may be too expensive and inappropriate. In this section, we present 4 robotic issues related to the context of the developing countries and, for each one, a solution that we propose as part of the AROUND project.

[5]For the moment, as support for our experimentations, we use Wifibot robots

A. Maintaining network connectivity in mobile multi-robots systems (MRS)

Problem description. Communication is one of the key issues in MRS as it is necessary for coordination and synchronization between robotic teammates. It is even more important in our context with cheap robots in order to enhance robustness. Let us consider robot team sent out to explore and build the map of some unknown area. To speed up the exploration, the robots should spread out as large as possible in the ground. On the other hand, they must keep in touch with each others for map sharing to avoid exploration overlaps. In other word, each robot has to plan its moves in a way so that it remains within the communication range of its teammates.

In a MANET[6], robot is not only an "ordinary" network node, but also a router relaying data for its neighbors. Data exchange between nodes is carried out through a routing path of intermediate consecutive nodes. Finding a routing path in the network for each pair of sender and receiver is in charge of a routing protocol providing that the path does exist. However, just as in the exploration application depicted earlier, information provided by MANET underlying services is not enough for robots to be aware of the global connectivity so that when they move, robots still remain connected to the team.

Our solution. In the context of the AROUND project, we proposed a solution [9] to this problem. Robots exchange messages to build an image of the full network topology. Although not completed, this knowledge is sufficient for robots to recognize which *local* links among those with their neighboring they should not break when planning a move.

In addition, the proposed solution should be decomposed into two main steps: (i) making robots acquire sufficient knowledge on the network connectivity – we coin the term *Connectivity Awareness*; and (ii) exploiting this knowledge in order to preserve the network connectivity while performing other tasks. The advantage of this separation is that the first step can be viewed as an application-independent abstraction, which can be incorporated into various connectivity maintenance strategies. In [9], we have illustrated the use of Connectivity Awareness for multi-robot exploration and for efficient verification of robust network connectivity in wireless network in general (network of robots is a particular case). Thus, we argue that the awareness of the network connectivity should be provided to robots as a basic networking service like routing in MANETs for example.

B. Dealing with pertubations during task allocations to robots

Problem description. Cheap robots have simple sensors, limited processing power and basic mechanic parts. They are more subject to failure than sophisticated one. In order to work efficiently they need to rely on robust wireless communication, remote computing for heavy processing and resilient organization. Failures of robots may be temporary (getting lost or stuck. . .) or complete (hardware breakdown, energy depletion. . .). Temporary failures mean that a robot will stop its useful activities until it recovers. As we demonstrated in [17], those failures have a huge impact on the efficiency of the task allocation algorithm. In previous work, we compared several patrol algorithms. A patrol task consists in gathering information in the environment, which is required for Search and Rescue activities. The robots must visit each region at regular intervals (homogeneous patrol) or follow given priorities (heterogeneous patrol, when some regions are more sensitive or must be visited before others). The patrol for a MRS is an instance of the task allocation problem, visiting a region being the atomic task.

Our solution. We made several proposals [17] to deal with this problem. Our starting point is a theoretically optimal patrol algorithm, based on a solution of the TSP (Traveling Salesman Problem) problem[2]. In a second proposal, each robot patrols its own territory, which is dynamically built, depending on the activities of the other robots. Finally, in a third proposition, the patrol algorithm relies on the building of artificial and local perception of the tasks priorities. Every region has its own priority to be visited (the time since the last visit for homogeneous patrol) which is propagated through the environment. The propagation can be made on a simulation or with the help of communicating devices spread in the environment. Robots have very simple decision to make: following the gradient of the artificial perception of the task priorities and visit the region at the local maximum of the gradient. The gradient depends also on the location of the robots, in order to spread the group.

In our experiments, both with a simulator and real robots, robots are suffering from two kinds of perturbations related to the cost of the robots. They must interrupt their patrol activities when (1) they need to recharge their batteries and when (2) they need to re-localize themselves (due to poor sensor mesurements). A perturbation typically last from 20 seconds to 20 minutes.

Results of the experiments show that the TSP based algorithm is the best when there is no perturbation (robots spend 100% of their time patrolling) but failed dramatically to deal with perturbations. The more perturbations exist, the more time is lost in reorganizing the group. In contrast, the artificial perception algorithm appears to be the more robust: the shape of the gradient changes when a perturbation occurs, or when a robot comes back to work, decisions are instantly changed if necessary, no reorganization is needed. An efficient patrol will seek to minimize the time between 2 visits in a given region of the environment. Therefore we based our evaluation on the avarage time between 2 visits for each region during a patrol experimentation.

C. Dealing with untrustworthy robots

Problem description. When we choose to use cheap robots, we have to be aware that their reliability is not as high as with more expensive robots, in particular as far as sensors are concerned. So it seems necessary to deal with this risk. Considering a patrol of robots collaboratively mapping a urban zone affected by a natural disaster, the objective of each robot

[6]Mobile Ad hoc NETwork

is usually to build the most complete, precise and reliable map of the environment, using as less as possible resources (time in particular). To map a territory, robots can detect the state of zones (where they move or in their direct vicinity) directly thanks to their sensors. They can also communicate in a limited range with other robots to exchange the necessary knowledge for building the map. Let assume that among the robots, some disturb the system by transmitting false or inaccurate information due to defectuous sensors.

Our solution. In order to reduce the disturbance introduced by these defectuous robots, we give our robots the ability to reason about other robots and to choose with which ones they want to interact. For this purpose, one of the most efficient tools is the concept of trust. Robots use trust in order to identify and isolate untrustworthy agents, to evaluate an interaction utility and to decide whether and with which partner to interact. Many computational trust models have been introduced in the artificial intelligence literature[14]. To improve the quality of the computed trust, our robots take into account both direct experience (they compare their own mapping information with mapping information received from other agents to compute a direct trust) and testimonies from other agents. As a basis of our work, we use the trust model suggested by Schillo *et al.* [16]. Following this model, robots communicate not only factual information (information about the environment) but also trusts they have in other robots. Thus robots can build a network of trust values transmitted by witnesses, called the TrustNet. We pretend that a good trust value for an agent towards another one can be computed as an aggregate of these two sets of information (mapping information and TrustNets). This merging process arises problems for which we propose some solutions in [11].

The computation of this trust has two uses for the robot. First, the robot can adapt its communication policy in real time: it chooses if it wants to go on communicating with this robot or if it sees it as defectuous and thus considers that it is more efficient not to (or partially) communicate with it. Then, the robot can associate a reliability value for each piece of mapping information received and accordingly create a fuzzy map, depending on information collected by itself and information received from other robots. The quality of the proposed solution will be evaluated by simulation on the quality of the map built by agents and on the system robustness against defectuous agents (e.g. by computing the quantity of sent messages). Some promising preliminary results are presented in [11].

D. Collecting images for managing disasters

Problem description. During the exploration of their environment, robots collect multiple images of the disaster scene. These images are intended for informing about the current situation in the scene and for managing the human rescue teams. All these images, or at least the images of interest, are sent over the robot network and centralized in a control center. There can be tenths, hundreds or even thousands of images arriving every minute, more than a human operator can analyze. Image information is completing information from other sources/sensors. But it is more difficult recognizing image content and extracting automatically relevant information from images. Therefore, there is a huge need in semi-automatic tools for decision support. Interactive tools are helping users for exploring images and for retrieving useful information. A problem here is to define what is “useful” information. This depends on the nature of the disaster, the kind of emergencies, the domain of the user (rescue domain, but can be political leader, fireman, medical aid, ...). It is difficult to define a priori which kind of information will be useful. The image exploration and retrieval system must be flexible, adaptive and capable of learning new concepts.

Our solution. Image exploration and retrieval has been studied for over a decade now, with some real successes, but still with many unsolved issues especially regarding what is called the “semantic gap”. We can define the semantic gap as the difference between the low level descriptors used to describe images for a computerized system and the high level definition of concepts used by human users for refering these images. Two current research directions can help solving this critical issue. The first one regards image representation using “visual words”, where local descriptors are extracted from images and codified in a dictionary [18]. This dictionary is defining a limited set of (low level) concepts for representing the images and thus help reducing the complexity of image description. Having defined a visual dictionary, we can adapt several methods already existing in the domain of text retrieval for indexing and retrieving images. The second research direction concerns relevance feedback, where the user is included in the retrieval loop for improving the final results. Depending on the context of the query, users can look for very different things using similar queries. So it is important to let the user improve the results in interaction with the system [15].

A query can be ponctual - results are interesting for a specific query, but are discarded after - or it may be persistant - information from the results should be learnt by the system to be used by subsequent users. The system should give the user the opportunity to identify concepts from images that will be learnt by the system (new keywords or classes from few retrieved images) and used later by other users (similar queries will be processed using image content and learnt annotations). Our current image description model is based on bag of visual words. From this, different retrieval schemes compatible with text and visual words have been tested [10]. The next step is to allow users to annotate images that they judge as pertinent after interacting with the system. For example, an user having retrieved images representing fire will annotate the group of retrieved images by providing a textual keyword. Then the system will identify appropriate visual words correponding to this textual keyword given by the user. In this example, only a small subset of images (answers retrieved by the user) are annotated. The annotation will then be propagated to other similar images [1].

Information retrieved by human operators are redirected to robots. Each image captured by a robot is GPS-localized

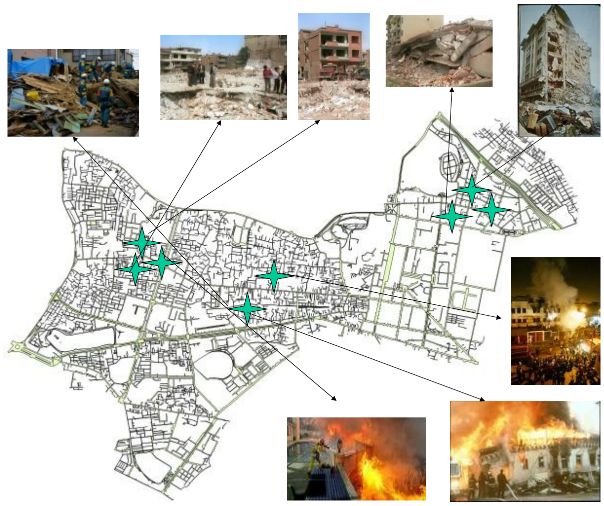

Fig. 2. Images collected by robots are GPS-localized in the disaster scene, which allow to retrieve information based on image content and image localization.

(see Figure 2) and retrieved images can be used to control new robot displacements in the field. Relevant images are identifying zones of interest to deploy robots in search of more information. This solution will be validated using a panel of human experts coming from different rescue-related domains.

V. Conclusion

This paper tackles the specificities of the developing countries in regard to disaster response. The AROUND project aims to explore this new situation with a 2-level architecture: a spatial decision support system at a global level and robot teams on the ground for the purpose of gathering information. At the opposite of the RoboCup Rescue project, which proposals are often sophisticated and expensive, we use cheap robots equipped with basic sensors, mainly cameras. This choice raises several problems related to robot communication, perturbation resilience and image processing. We have reported here our first results obtained in the above domains.

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[7]French Ministry of Foreign Affairs/INRIA/CNRS

References

[1] S. Barrat and S. Tabbone. Classification and automatic annotation extension of images using bayesian network. In *Proceedings of the Joint IAPR International Workshops on Structural and Syntactic Pattern Recognition (SSPR 2008) and Statistical Techniques in Pattern Recognition (SPR 2008)*, pages 937–946, 2008.

[2] Y. Chevaleyre, F. Sempé, and G. Ramalho. A theoretical analysis of multi-agent patrolling strategies. In *Autonomous Agents and Multi-agent Systems Conference, AAMAS-2004, New York*, pages 1524–1525, 2004.

[3] T. Chu, A. Boucher, A. Drogoul, D. A. Vo, H. Nguyen, and J. Zucker. Interactive learning of expert criteria for rescue simulations. In *PRIMA*, 2008.

[4] M. Dias, G. Mills-Tettey, and T. Nanayakkara. Robotics, education and sustainable development. In *IEEE International Conference on Robotics and Automation (ICRA)*, 2005.

[5] S. El-Masri and G. Tipple. Natural disaster, mitigation and sustainability: The case of developing countries. *International Planning Studies*, 7(2):157–175, 2002.

[6] P. Guyot, A. Drogoul, and S. Honiden. Power and negotiation: lessons from agent-based participatory simulations. In *Proceedings of the fifth international joint conference on Autonomous Agents and Multi-Agent Systems (AAMAS)*, pages 27–33, 2006.

[7] N. Huan. Vietnam coastal zone vulnerability assessment. Technical report, Center for Consultancy and Technicl Support of Meteorology, Hydrology and Environment, Hanoi, Vietnam, 1996.

[8] H. Kitano, S. Tadokoro, I. Noda, and H. Matsubara. Robocup rescue: Search and rescue in large-scale disasters as a domain for autonomous agents research. In *Proceedings of the IEEE Conference on Man, Systems, and Cybernetics*, 1999.

[9] T. V. Le, N. Bouraqadi, V. Moraru, S. Stinckwich, and A. Doniec. Making networked robot connectivity-aware. In *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, pages 3502–3507, 2009.

[10] N. V. Nguyen, J.-M. Ogier, S. Tabbone, and A. Boucher. Text retrieval relevance feedback techniques for bag of words model in cbir. In *Proceedings of the International Conference on Machine Learning and Pattern Recognition (ICMLPR)*, July 2009.

[11] Q. A. Nguyen Vu, B. Gaudou, R. Canal, and S. Hassas. Coherence and robustness in a disturbed multi-agents system,. In *Proceedings of IEEE-RIVF 09*, Da Nang City, Viet Nam, 2009.

[12] N. H. Phuong. *Development of a decision support system for earthquake risk assessment and loss mitigation using GIS*, volume 7, pages 62–78. Contribution of Marine Geology and Geophysics, 2003.

[13] PNUD, editor. *La réduction des risques de catastrophes. Un défi pour le développement*. Programme des Nations Unies pour le développement (PNUD), 2004.

[14] J. Sabater and C. Sierra. Review on computational trust and reputation models. *Artificial Intelligence Review*, 24(1):33–60, September 2005.

[15] S. Santini, A. Gupta, and R. Jain. Emergent semantics through interaction in image databases. *IEEE Transactions on Knowledge and Data Engineering*, 13:337–351, 2001.

[16] M. Schillo, P. Funk, and M. Rovatsos. Using trust for detecting deceitful agents in artificial societies. *In Applied Artificial Intelligence, Special Issue on Trust, Deception and Fraud in Agent Societies*, 14(8):825–848, September 2000.

[17] F. Sempé. *Auto-organisation d'une collectivité de robots : Application à l'activité de patrouille en présence de pertubations*. PhD thesis, Paris 6, 2004.

[18] J. Sivic and A. Zisserman. Video Google: A text retrieval approach to object matching in videos. In *Proceedings of the International Conference on Computer Vision (ICCV)*, volume 2, pages 1470–1477, Oct. 2003.

[19] S. Tadokoro, T. Takamori, K. Osuka, and S. Tsurutani. Investigation report of the rescue problem at Hanshi-Awaji earthquake in Kobe. In *Proceedings of the 2000 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 1880–1885, 2000.

[20] United Nations. *World Conference on Disaster Reduction*, January 2005.

[21] P. Villegas. Flood modeling in perfume river basin, Hue province, Vietnam. Master's thesis, International Institute for Geo-Information Science and Earth Observation, Enschede, Netherlands, 2004.