Taxonomy of Navigation for First Responders

Zhiyong Wang and Sisi Zlatanova

Abstract Navigation services are gaining much importance for all kind of human activities ranging from tourist navigation to support of rescue teams in disaster management. With the frequent natural disasters occurring in recent years, emergency navigation for first responders poses a set of serious challenges for researchers in the navigation field. The chapter introduces a taxonomy of navigation among obstacles, categorizes navigation cases on basis of type and multiplicity of first responders, destinations, and obstacles, and reviews related research. This review reveals limitations in current navigation research and challenges that have not been explored yet. We also briefly present our approach using agent-based technology, real measurements and web technologies for the development and implementation of navigation systems that aim at navigating first responders among both static and moving obstacles. Finally, we conclude by providing views on further investigations and developments.

Keywords Taxonomy · Navigation · First responders

1 Introduction

Advances in geographic positioning technologies and the popularity of communication methods such as Internet and ad hoc network have fueled widespread adoption of Location-based services (LBS) in many everyday situations, especially in emergency response scenarios. LBS applications have shown the potential to be

Z. Wang (✉) · S. Zlatanova
OTB Research Institute for the Built Environment, TU delft, Jaffalaan 9, 2628BX Delft, The Netherlands
e-mail: Z.Wang-1@tudelft.nl

J. M. Krisp (ed.), *Progress in Location-Based Services*,
Lecture Notes in Geoinformation and Cartography, DOI: 10.1007/978-3-642-34203-5_17,

a valuable addition in disaster management (DM), providing a variety of services that facilitate rapid response (Togt et al. 2005). Typical examples of these services are location and navigation. Disaster managers must be able to keep track of their locations. Location information of moving objects such as first responders can be obtained through various outdoor and indoor localization technologies like GPS, wireless local area network (WLAN), radio frequency identification (RFID) and ultrasound range sensors (Khoury and Kamat 2009; Girard et al. 2011; Li and Becerik-Gerber 2011). The frequent changes of large amount of location information demand an efficient management of moving objects which have been intensively studied by many researchers (Sistla et al. 1997; Wolfson et al. 1998; De Almeida and Güting 2005; Meratnia 2005). Besides, rescue teams must be able to be re-routed around dangerous areas to reach safety quickly if conditions change. How to assist users in navigation has been the focus of considerable research effort over the past decades, but some problems still need to be addressed.

Although over the years researchers have put much effort into utilization of location information for navigation purpose, navigation for first responders brings forwards requirements of a higher level, e.g., the coordination among first responders, the incorporation of the obstacles information and the development of corresponding algorithms to deal with these information, all of which are not met by existing navigation developments. Many commercial navigation systems (e.g., Tom–Tom, Mio, Garmin) are designed and developed to provide personalized routing services, and some of them are even able to incorporate information about traffic congestions and suggest alternative routes. However, these systems do not take into account specific emergency response requirements, which result in poor performance in response to disasters. The navigation service provided by existing emergency support systems (Johnson 2008; Parker et al. 2008) are capable of finding the shortest route to a certain location, taking the damages of the infrastructure into account, but lack consideration of real-time information of disasters, which brings serious limitations when applying these systems to disasters that affect road network dynamically. For instance, in response to a real contaminant plume, the emergency response units should not be guided right through the toxic plume by their route planners. This kind of changing plumes can be considered as moving obstacles with changing location and shape that cause temporary blocks of road segments. Although some navigation algorithms have been developed for avoiding moving obstacles, they have not been implemented in the software for emergency response yet due to their insufficiencies. In addition to that, most traditional navigation systems are dedicated to routing for only one response unit with a pair of starting and ending points. But in many emergency situations, response units need to cooperate and perform tasks together. They not only need to obtain individual routes but also take into consideration other units in the area. For example, in the case of emergency medical service, there is a need for a better organization within the hospitals concerning the deployment of paramedics, availability of medical supplies, transportation, and equipments. Ambulances have to deliver several patients to different destinations which can either be static or dynamic in some situations.

This work represents the first step of an approach to support emergency navigation among obstacles for first responders. Our main focus is to propose path-finding methods taking into account both static and moving multiple obstacles. This chapter presents a taxonomy of navigation cases and a set of analysis related to optimal navigation for mobile rescue units. Although prior studies have paid little attention to the emergency navigation among obstacles, various similar studies have been conducted in the field of mobile robot navigation and different kinds of approaches to assist path finding among static/moving obstacles have been proposed (Bowling and Veloso 1999; Zu et al. 2004; Kunwar et al. 2006; Belkhouche et al. 2007; Undeger and Polat 2010), which provide potential opportunities for developing navigation-related solutions for disaster management.

The organization of the chapter is as follows. Firstly, we introduce a taxonomy of navigation for first responders and present selected criteria for our taxonomy. In the following sections, we divide all navigation cases into two broad categories according to the characteristic of obstacles: static obstacles and moving obstacles. Then we briefly review related publications that fit in each case. After that, we present our approach to the problem of navigating first responders among moving obstacles and describe the architecture of our proposed navigation system. Finally, we conclude this chapter and present views on future directions.

2 Taxonomy of Navigation with Obstacles

A number of researchers have addressed issues related to navigation. Advances in various areas such as engineering, computer science, applied mathematics, etc. provide significantly rich solutions to navigation related issues, although their focus and applications can differ considerably. Similar research on robotic navigation considering static/moving obstacles have been considerably investigated for path planning for robots (Bowling and Veloso 1999; Yang et al. 2006; Belkhouche et al. 2007; Li et al. 2009; Undeger and Polat 2010; Ni and Yang 2011). Research results from these work could benefit the research on navigation for first responders in some aspects. For example, Kulich et al. (2004) make use of ant colony algorithms to assign moving objects to multiple target locations. Yang et al. (2006) proposes some methods for finding a suitable collision-free path. However, little attention has been paid to the routing problem for multiple first responders in the context of obstacles caused by disasters. Most path finding algorithms that are designed for solving obstacle-avoiding problems deal with only one moving object given a pair of starting and end points (Mitchell et al. 1992; Mitchell 1993; Kapoor et al. 1997; Li and Klette 2006; Visser 2009; Nedkov and Zlatanova 2011).

Furthermore, the related work on robot navigation mostly focuses on path planning in free space, but does not take into consideration constrains of the real road network. Besides, the considered obstacles are often stationary, which can not reflect the dynamics of physical phenomena (flood, plume, fire, etc.) that cause disasters. (Mitchell et al. 1992; Mitchell 1993; Van Bemmelen et al. 1993; Kapoor et al. 1997; Li and Klette 2006; Nedkov and Zlatanova 2011). Since the status of the road network varies with the disasters over time, it is necessary to take into consideration the moving obstacles in the path finding process. Moreover, the first responders work in groups and cooperate with each other to achieve the common goal (e.g., searching for the survivors within an area affected by disasters), the coordination between their paths should also be considered.

In order to understand navigation cases in disasters, we need to categorize them and break them down into their lower-level classes. More importantly, by introducing a comprehensive review of categories, we can gain a greater understanding of characteristics and differences of these cases and study them separately. This taxonomy also encourages the design of new techniques by taking advantage of achievements in relevant fields. In previous navigation research, Zlatanova and Baharin (2008) present a taxonomy of navigation, trying to structure this field into different categories. Nevertheless, this classification does not take into account the obstacles. The aim of this work is to explore possible navigation scenarios in disasters by constructing this taxonomy.

Instead of a strict classification (which is very difficult to provide), we offer some broad keywords and phrases that characterize some classes of these cases. We assume that: (1) We deal with moving objects (e.g., responders), but they start moving at a given time and from given positions (2) We have multiple obstacles, i.e., if the routing works well to avoid many obstacles, it should be able to deal with the environment with one obstacle as well. Following these assumptions, we have identified the following criteria and distinguish the cases in the form of a quadruple:

$$X = \langle X_1, X_2, X_3, X_4 \rangle$$

where

- $X_1 \in \{o, m\}$ is the number of responders (one or many)
- $X_2 \in \{O, M\}$ represents the number of destinations (One or Many)
- $X_3 \in \{S, D\}$ is the type of destinations (Static or Dynamic)
- $X_4 \in \{s, m\}$ corresponds to the type of obstacles (static or moving)

For example, one case denoted by $\langle o, M, D, m \rangle$ means one moving object has to be routed to many dynamic destinations, avoiding many moving obstacles.

We offer an overview of work that fits to each case and illustrate its potential application to emergency response. We do not claim that this taxonomy is explicit, since further refinements can be performed if adding more criteria, e.g., the obstacle can change its shape or not; the movement of the obstacle can be a priori known or not; the obstacle can have either distinct boundaries or fuzzy shape due to the nature of disasters. However, most current navigation cases fit into our taxonomy.

3 Navigation Cases with Static Obstacles

In the following section, we mainly consider the navigation problems that deal with static obstacles.

3.1 One Moving Object has to be Routed to One Static Destination, Avoiding Many Static Obstacles $\langle o, O, S, s \rangle$

This is a typical example of the rescue operation when a large-scale disaster occurs. The rescue team has to be routed through an affected area of which some segments are not passable. This case has been well studied in computational geometry, which is to compute an optimal obstacle-avoiding path in a geometric context. The most basic form of the problem is: Given a collection of obstacles, find a Euclidean shortest obstacle-avoiding path between two given points. By considering several parameters that define the problem, a broader collection of problems has been defined and investigated, and accordingly various algorithms have been proposed (Li and Klette 2006; Mitchell et al. 1992; Mitchell 1993; Kapoor et al. 1997). The case for real road network is also studied. Schmitz et al. (2008) present an example of utilizing OpenStreetMap (http://www.openstreetmap.org) data for the disaster management operation. A web-based route service called OpenRouteService (http://openroute-service.org) is developed to provide route planning services taking blocked areas or streets into account. For similar purpose, Nedkov and Zlatanova (2011) propose a method for performing shortest path calculations taking constraints and obstacles into account. The A* path-finding algorithm is used to guide Google's Directions Service around obstacles (see Fig. 1).

3.2 One Moving Object has to be Routed to Many Static Destinations, Avoiding Many Static Obstacles $\langle o, M, S, s \rangle$

This situation may occur when a rescue unit has to visit multiple emergency locations within an affected area. For example, a fleet of rescue trucks is sent to deliver relief goods to several affected locations after a strong earthquake. The information of severely damaged transportation infrastructure is essential in the routing for this emergency response service. This problem can be addressed as a variant of the traveling salesman problem (TSP), the goal of which is to plan a trip with least cost in an environment with obstacles. Faigl (2011) proposes two self-organizing map (SOM) algorithms for the TSP which are examined in the multi-goal path planning problem motivated by inspection planning in the polygonal domain that contains obstacles. The first is Somhom's algorithm, and the second is the Co-adaptive net. The authors improve the algorithms using modifications of

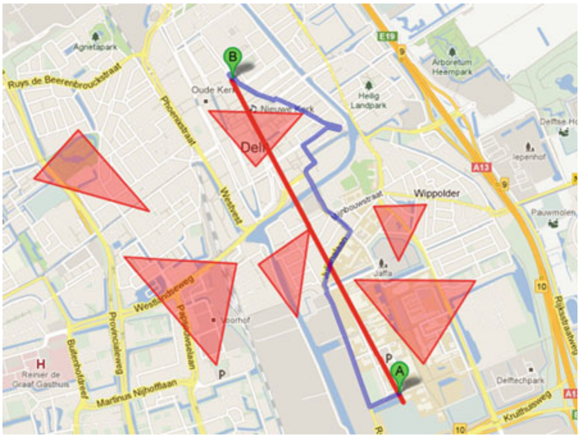

Fig. 1 Calculated route result (from Nedkov and Zlatanova 2011)

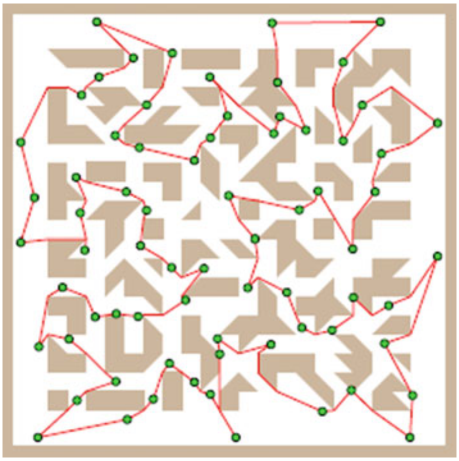

Fig. 2 Selected solutions found by the modified Somhom's algorithm, the small disks represent cities (from Faigl 2011)

recent adaptation rules and by new proposed improvements, which significantly reduce the required computational time. One of selected solutions found by the modified Somhom's algorithm is presented in Fig. 2.

3.3 Many Moving Objects have to be Routed to One Static Destination, Avoiding Many Static Obstacles $\langle m, O, S, s \rangle$

This situation often takes place after the occurrence of disasters. A classical example is that several fire trucks have to be routed to a fire location through a road network damaged by earthquake or flood. This problem can be split into sub-problems by navigating moving objects separately, which can be addressed by approaches proposed for $\langle o, O, S, s \rangle$. We can also extend this problem by

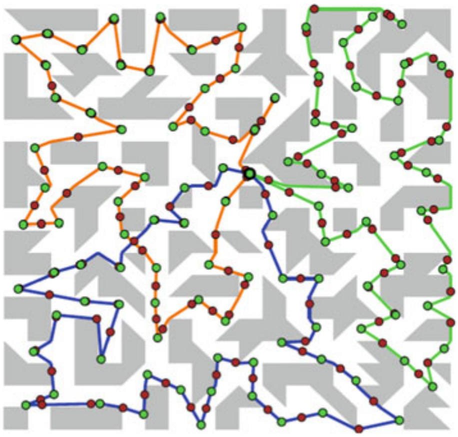

Fig. 3 The best solution found for 3 agents in the map with 100 cities, obstacles are in grey (from Kulich et al. 2004)

considering moving objects as moving obstacles. In this extended case, each moving object takes into account other moving objects in its path planning to avoid potential collisions. This extended problem can be re-formulated into the problem that arises in the case $\langle m, O, S, m \rangle$.

3.4 Many Moving Objects have to be Routed to Many Static Destinations, Avoiding Many Static Obstacles $\langle m, M, S, s \rangle$

This is the case that often takes place when major disasters strike. Several rescue teams are dispatched to perform tasks in different places or to transport a large amount of materials to the disaster areas. Substantial efforts have been made to provide the optimal set of routes for fleets of relief vehicles. The difficulty of this problem arises when obstacles are taken into consideration. Intelligent algorithms with improvements provide a promising approach to overcome this difficulty. Kulich et al. (2004) apply three soft computing techniques—ant colony optimization, genetic algorithms, and neural networks to rescue operation planning that can be restated as the multiple traveling salesmen problem (MTSP): given N cities and A agents, find an optimal tour for each agent so that every city is visited exactly once. It improves the selected techniques by introducing suitable heuristics and applies the implemented solutions in large areas with obstacles (see Fig. 3).

3.5 One Moving Object has to be Navigated to One Dynamic Destination, Avoiding Many Static Obstacles $\langle o, O, D, s \rangle$

The situation appears when one responder pursues one victim moving in a road network, parts of which are damaged and not accessible. This also happens in the

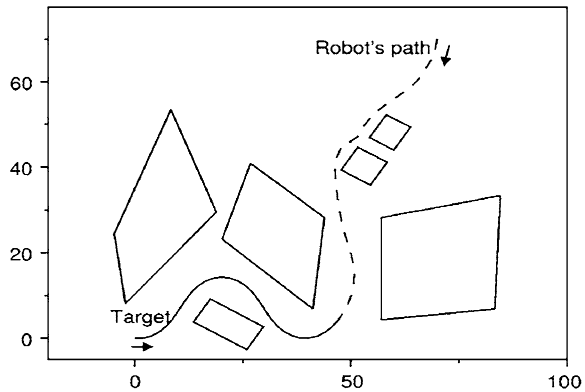

Fig. 4 Robot's navigation toward a goal moving in a sinusoidal motion in the presence of obstacles (from Belkhouche et al. 2007)

free space of a building in which corridors can be blocked by collapsed ceilings or floors. Some researchers have been working on robot navigation in free space. Belkhouche et al. (2007) present a method for robot navigation toward a moving object in presence of static obstacles. The proposed method integrates two navigation modes, parallel navigation mode which is to design a control strategy for the robot in order to reach the moving target, and obstacle-avoidance mode which is to avoid local obstacles. Figure 4 shows that the navigation strategies help robot to successfully reach the moving target under some conditions.

3.6 Many Moving Objects have to be Routed to One Dynamic Destination, Avoiding Many Static Obstacles $\langle m, O, D, s \rangle$

This may occur if many first responders have to be routed through a transportation infrastructure ravaged by disasters to meet somewhere to exchange equipment or transfer the wounded. The responders have to pursue a meeting point that changes with traffic conditions, which needs effective coordination between them, or police cars need to stop a criminal trying to escape. This problem can be seen as an extension of the well-known Pursuit-Evasion (PE) problem with obstacles. Undeger and Polat (2010) address the problem of multi-agent pursuit in an environment full of obstacles. They propose an algorithm called Multi-Agent Real-Time Pursuit (MAPS) for multiple predators to capture a moving prey (see Fig. 5). MAPS employs two coordination strategies, blocking escape directions (BES) and using alternative proposals (UAL), to help the predators waylay the prey in possible escape directions.

3.7 One Moving Object has to be Navigated to Many Dynamic Destinations, Avoiding Many Static Obstacles $\langle o, M, D, s \rangle$

$\langle o, M, D, s \rangle$ happens when a response unit is sent to rescue multiple victims that fleet using traffic facilities hit by natural disasters. In this situation, the response unit

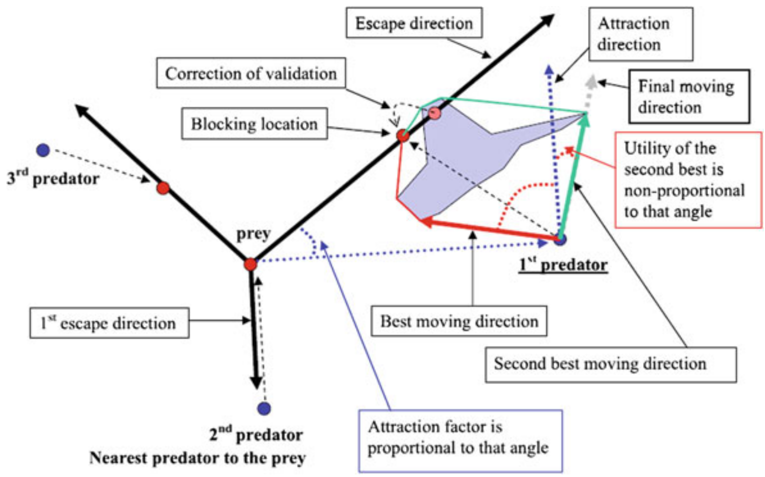

Fig. 5 A complete sample illustrating the entire process of MAPS (from Undeger and Polat 2010)

can be considered as an interceptor and has to be navigated to pursue many targets whose positions change with the change of conditions. This problem has also been studied in robot navigation and a method proposed by Kunwar et al. (2006) for pursuing multi targets taking into account the environment with static and/or moving obstacles will be described in the case $\langle o, M, D, m\rangle$ (see next section).

3.8 *Many Moving Objects have to be Routed to Many Dynamic Destinations, Avoiding Many Static Obstacles* $\langle m, M, D, s\rangle$

The situation becomes more complex when several responders starting from different positions have to meet at a series of dynamic locations to perform their tasks, avoiding static obstacles. Three basic problems have to be taken into account: (1) path planning; (2) coordination that helps reach the meeting points efficiently; (3) obstacles avoidance. Similar problems in robot navigation have been investigated by Ni and Yang (2011). They propose an approach based on a bioinspired neural network for the real-time cooperative hunting by multi-robots, where the obstacles are linked with different shapes. The bioinspired neural network is used for cooperative pursuing by the multi-robot team. Simulation results demonstrate that the proposed approach can deal with the situations of multiple evaders and can dynamically change the pursuing alliances to guarantee that all the evaders can be caught efficiently.

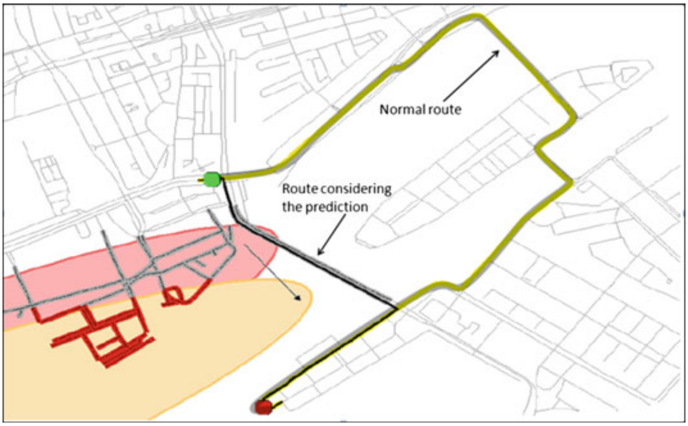

Fig. 6 Route considering the prediction versus normal route (adapted from Visser 2009)

4 Navigation Cases with Moving Obstacles

Based on the literature reviewed, navigation cases with moving obstacles are presented in the following way:

4.1 *One Moving Object has to be Routed to One Static Destination, Avoiding Many Moving Obstacles* $\langle o, O, S, m \rangle$

This may happen when one first responder has to go through an area affected by many moving obstacles (e.g., plume) simultaneously. In this case, the prediction of moving obstacles should be incorporated into the route determination process. Visser (2009) proposes a path-finding approach that takes into account changes in the road network and predictions of future situations. The Dijkstra algorithm is extended to incorporate the routing with predictions of plume movement and bridge openings and closings, and to decide whether it is better to wait or take an alternative route. An example of routing with predictions for one moving obstacle is shown in Fig. 6.

4.2 *Many Moving Objects have to be Routed to One Static Destination, Avoiding Many Moving Obstacles* $\langle m, O, S, m \rangle$

A typical example of this situation is guiding a certain amount of fire trucks to one emergency location. The system should not only compute the routes for all

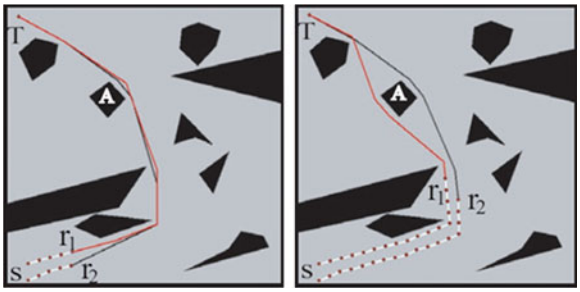

Fig. 7 Path planning for 2 robots with the same target (from Yang et al. 2006)

trucks but also coordinate their paths to avoid traffic congestions or possible collisions by considering other moving objects as obstacles. Some researchers in robotics have been doing research on this topic. Yang et al. (2006) propose a knowledge based genetic algorithm (GA) for on-line path planning of multiple mobile robots in dynamic environments. The proposed GA uses a unique problem representation method to represent the environments with complex obstacle layouts and obstacles can be of arbitrary shapes. An evaluation method is developed specially for accurately detecting collisions among robot paths and obstacles, and assigns costs that are effective for the proposed algorithm. Figure 7 shows the simulation results of path planning for two mobile robots with the same target.

4.3 One Moving Object has to be Routed to Many Static Destinations, Avoiding Many Moving Obstacles $\langle o, M, S, m\rangle$

One classical example is navigating a rescue team to search several places within an area struck by disasters. The navigation system must be able to plan a trip connecting these locations in the dynamic environment, which can be addressed as a dynamic version of TSP. An ant colony optimization (ACO) approach for this dynamic TSP is proposed by Guntsch et al. (2001) to provide a good solution whose quality is averaged over time. A certain amount of cities are deleted or inserted at different frequencies. As shown in Fig. 8, one city is inserted and one city is deleted. The changes of cities could be caused by the moving obstacles in the environment. The authors investigate three different strategies, i.e., Restart-Strategy, η-Strategy and τ-Strategy, for pheromone modification in reaction to changes of the problem instance. They also extend these strategies by combining some of them and proposing a heuristic for keeping a modified elitist ant. The results show their approach can find better solutions for a variety of problem classes than the pure strategies.

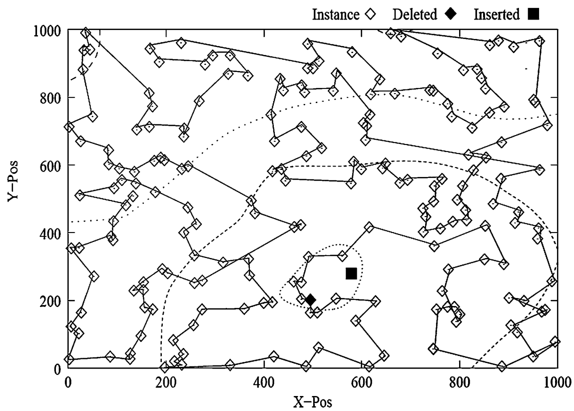

Fig. 8 TSP test instance with best solution (from Guntsch et al. 2001)

4.4 Many Moving Objects have to be Routed to Many Static Destinations, Avoiding Many Moving Obstacles $\langle m, M, S, m\rangle$

This navigation problem can be considered as a generalization of TSP, where more than one salesman is allowed to be used in the solution and many moving obstacles exist in the environment. It has practical application in disaster management when disasters (e.g., fire, plume) occur and rescue groups are sent to multiple places to alert or rescue local citizens. The problem is characterized by a dynamical environment and coordination between rescue groups. Li et al. (2009) propose an approach for a multi-robot path-planning problem with the same characteristics. Multiple robots have to coordinate in the workspace while avoiding moving obstacles. A neural-network-based intelligent planner is designed for the coordination of multiagent systems (MASs). The landscape activities of the neural network represent the dynamics of the workspace included with moving obstacles. Simulation results demonstrate the capability of the proposed approach in planning the paths in presence of moving obstacles.

4.5 One Moving Object has to be Navigated to One Dynamic Destination, Avoiding Many Moving Obstacles $\langle o, O, D, m\rangle$

This case $\langle o, O, D, m\rangle$ is similar to the case $\langle o, O, D, s\rangle$. The only difference is that rescuers work in an area with dangerous moving obstacles, which poses a new challenge for researchers. Masehian and Katebi (2007) present a method for generating collision-free near-optimal paths for mobile robots pursuing a moving target amidst both dynamic and static obstacles. They introduce a new concept called Directive Circle (DC) which can prevent the robot from being trapped in deadlocks or local minima. The speeds of dynamic obstacles are calculated online, which requires sufficient robot's sensors in terms of the number and coverage.

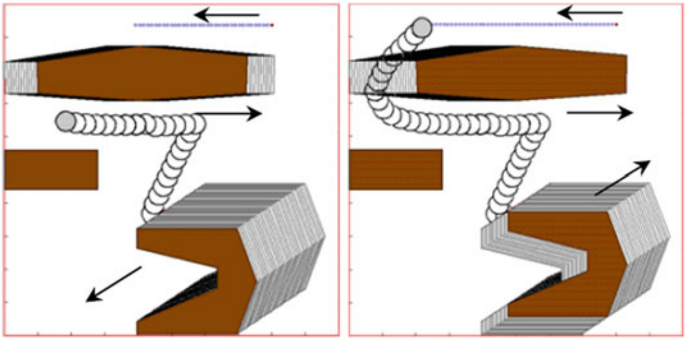

Fig. 9 Collision-free trajectories of robot that pursuits a moving target in an environment with one static and two moving obstacles (from Masehian and Katebi 2007)

As shown in Fig. 9, the proposed method is capable of coping with static and moving obstacles.

4.6 Many Moving Objects have to be Routed to One Dynamic Destination, Avoiding Many Moving Obstacles $\langle o, O, D, m \rangle$

Such situation could occur when many response units have to meet at a certain point which can change with the dynamic situation. The moving obstacles can either be disasters (e.g., plume, fire) or crowds. This is also a variant of the PE problem, where multiple pursuers (responders) must coordinate their moves to jointly capture the evader avoiding moving obstacles. Similarly, in a multi-robot game, robots in a robotic team have to achieve a specific goal avoiding other opponent robots which can be viewed as obstacles. Bowling and Veloso (1999) introduce a motion control algorithm, which allows a team of general differential-driven robots to accurately reach a moving target point in an environment with multiple moving obstacles.

4.7 One Moving Object has to be Navigated to Many Dynamic Destinations, Avoiding Many Moving Obstacles $\langle o, M, D, m \rangle$

This is similar to the aforementioned situation $\langle o, M, D, s \rangle$, but the considered environment is more complex including multiple moving obstacles. As mentioned above, a novel method for the interception of moving targets in the presence of static and/or mobile obstacles is proposed by Kunwar et al. (2006). The proposed method provides simultaneous positional interception and velocity matching of the target moving in a dynamic environment with obstacles. An acceleration command for the autonomous robot (i.e., interceptor) is computed from a rendezvous-guidance technique that considers the kinematic and dynamic limitations of the interceptor, which can be extended to the application of intercepting a set of multiple targets.

4.8 Many Moving Objects have to be Routed to Many Dynamic Destinations, Avoiding Many Moving Obstacles $\langle m, M, D, m \rangle$

This is the most complex case. The responder vehicles have to go through an area affected by several moving obstacles to meet at some dynamic points. This problem may be reduced to a path-planning problem with equal number of vehicles and targets which could be addressed by the algorithm proposed by Zu et al. (2004). They investigate path planning for multi-vehicle multi-target pursuit (MVMTP) and propose a global cost function (GCF) for an optimal one-vehicle-one-target-pair appointment. Each appointed pair uses artificial potential (AP)-guided evolutionary algorithm (EA) to search the path that allows the vehicle to catch the target at a specified criterion while avoiding moving obstacles.

5 Discussion

In this taxonomy, we concentrate on the navigation cases that involve one/many moving objects, one/many static/dynamic destinations and many static/moving obstacles. Table 1 shows a summary of the taxonomy of navigation cases. Many of the cases listed in the table have been investigated by previous studies. In the table, we list 3 aspects of interest, which are separately assigned to one column of the table. The column with the heading "Problem Type" gives the type of the navigation problem: shortest path problem (SPP), pursuit-evasion (PE) problem and traveling salesman problem (TSP). The next column with the heading "Environment Type" indicates whether any investigation has been conducted on the case corresponding to each listed environment type. The last column with the heading "Application Domain" tells if any relevant research on each navigation case have been studied in the concrete application domain. A tick ($\surd$) denotes that it is under investigation, while a cross (x) denotes no investigation is found and a dot (•) means uncertain. As indicated in Table 1, there are 4 navigation cases where typical shortest path routing is applicable. Totally 8 navigation cases associated with dynamic one/more destinations can be seen as generalizations of the PE problem and have been intensively applied in robotics. The other 4 cases with multiple static destinations can be considered as extended TSP problems. Although there are many methods developed for routing with obstacles, most of them are proposed in the mobile robot navigation domain and only a few approaches can be

Table 1 Summary table of navigation taxonomy

	Navigation case	Problem type	Environment type		Application domain	
			Road network	Free space	Emergency response	Robotics
Navigation cases with static obstacles	⟨o, O, S, s⟩	SPP	√	√	√	√
	⟨o, M, S, s⟩	TSP	x	√	x	•
	⟨m, O, S, s⟩	SPP	x	•	x	•
	⟨m, M, S, s⟩	TSP	x	√	√	•
	⟨o, O, D, s⟩	PE	x	√	x	√
	⟨m, O, D, s⟩	PE	x	√	x	√
	⟨o, M, D, s⟩	PE	x	√	x	√
	⟨m, M, D, s⟩	PE	x	√	x	√
Navigation cases with moving obstacles	⟨o, O, S, m⟩	SPP	√	√	√	√
	⟨m, O, S, s⟩	SPP	x	√	x	√
	⟨o, M, S, m⟩	TSP	x	•	x	•
	⟨m, M, S, m⟩	TSP	x	√	x	√
	⟨o, O, D, m⟩	PE	x	√	x	√
	⟨m, O, D, m⟩	PE	x	√	x	√
	⟨o, M, D, m⟩	PE	x	√	x	√
	⟨m, M, D, m⟩	PE	x	√	x	√

applied to obstacle-avoiding routing for emergency response. All in all, we present 16 cases there, but, to the best of our knowledge, only two of these cases, i.e., $\langle o, O, S, s\rangle$, $\langle o, O, S, m\rangle$ have been studied with consideration of constraints of road network by previous research. The remaining cases should be further investigated and there are many open issues that still need to be explored in navigating first responders in the road network with obstacles.

6 Proposed Approach

In our study, we focus on navigation among moving obstacles for multiple first responders. These are the eight cases in the second half of Table 1. We believe the approaches for moving obstacles can be also applied to the problem with static obstacle by setting the moving obstacles' velocity to zero. Furthermore, most emergency responses take place in the outdoor environment, which require navigation services working in real road networks. Currently, our work is limited to the cases including only static destinations. Since navigation problems with both static destinations and static obstacles can be converted to well-known transportation problems by adapting the transportation cost, our research will concentrate on the routing in the road network with static destinations and moving obstacles, and will adapt existing routing algorithms for obstacle-avoidance purposes. As shown in Table 1, with respect to the cases with only one target location (i.e.,

$\langle o, O, S, m \rangle$ $\langle m, O, S, m \rangle$), shortest path algorithms with modifications have been proposed and can be applied to find optimal or near- optimal routes. Therefore we are going to investigate the other two cases, i.e., $\langle o, M, S, m \rangle$ and $\langle m, M, S, m \rangle$. These problems can be seen as various extensions of the TSP. Although previous research (Guntsch et al. 2001; Li et al. 2009) on the same topics existed, they lack consideration of the road network and simulation with real-time measurements, which limit the application of their methods in the navigation aid for first responders. To address these two aspects, we intend to integrate various algorithms with web mapping technologies and agent-based modelling and simulation, which will be corrected with real-time data via sensors and the web. We believe that the agent-based simulation system can facilitate emergency navigation in at least two aspects: (1) the simulation itself has the ability to predict "future" situations with the "current" states as input, serving as a tool for achieving situation awareness; (2) the agent-based simulation could help responders evaluate the routing plan and modify it if necessary. As traditional simulation models based on rigid input parameters, which make little usage of real-time data, fail to reflect the real disaster behaviors and reduce their ability of predictions, we will explore the way to update simulation systems by means of real-time measurements and information to make it capable of adapting itself dynamically to the constant changes of environment conditions. Such capabilities promise more accurate analysis and prediction, and more reliable outcomes that we can use for real-time emergency navigation support. The real-time information can be obtained by sensor measurements (GPS tracking of emergency responders, pollution sensors, filed measurements) or by crowd-sourcing. The advent of the web mapping technologies facilitates the dissemination of data to responders. Building the system on top of these web mapping technologies enable the response community to easily and quickly share their emergency plans and to work collaboratively.

Figure 10 illustrates the intended prototype system, which consists of several components: data collection, data management, agent-based simulation model and visualization of simulation results. Real-time information with respect to disasters and real-time position data about the moving objects (i.e., first responders) will be structured to drive and update the simulation model. The agent-based simulation model will be connected to the disaster model updated with real-time data. The disaster is visualized in the form of one or more moving polygons crossing a certain road network (see Fig. 11). First responders will be modeled as mobile agents who can use heuristics algorithms to computes the routes. A database is used for data management and to store the geo-information of the network, the information of mobile agents (the routes, current position, starting point, end point, the status, etc.) and the real-time data. 2D/3D GIS data (e.g., OpenStreetMap) will be used to model the spatial environment, especially the road network, and to obtain details about the objects within the environment. The simulation output data will be displayed to users through web application technologies.

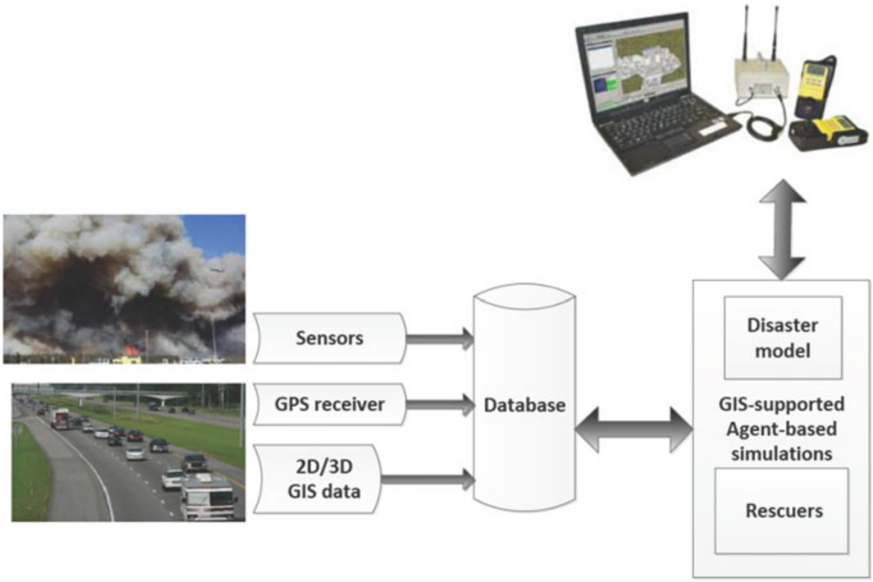

Fig. 10 The architecture of the prototype system

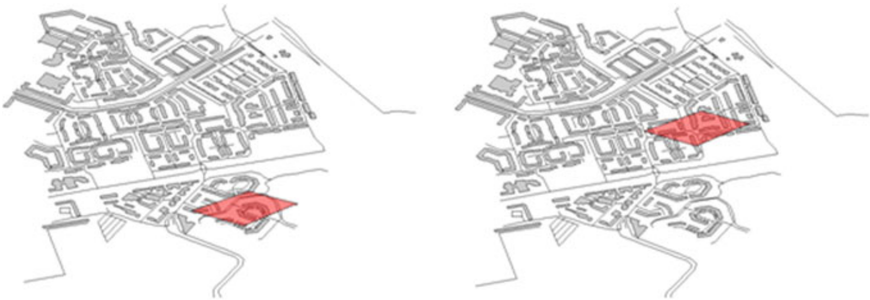

Fig. 11 Snapshot of disaster simulation

7 Summary and Outlook

This chapter concentrates on navigation aids for first responders among obstacles. We provide a taxonomy of navigation broadly classifying the cases with obstacles and briefly describing existing approaches proposed in various domains for navigating moving objects in the environment populated by a set of static or moving obstacles. We also present a system architecture within which the obstacle-avoiding routing algorithms can be designed, implemented and tested through simulations. The main components of the proposed system architecture are agent-based modelling simulation and sensor measurements delivered via web-based technologies. Such an approach will also allow evaluating computed navigation results.

In spite of the long history of routing and navigation, research on navigation for first responders is largely in its beginnings. Compared to its counterpart in robotics where a rich set of navigation approaches has been developed to deal with obstacles, many issues of obstacle-avoiding routing in road network are open for further investigation. The focus of this research is on navigating multiple responders to multiple static destinations avoiding multiple moving obstacles. Various aspects need to be investigated: communications between the agents to enrich the situational awareness, strategies for avoiding obstacles (choose a longer way or wait for the obstacle to move), strategies for completing tasks, etc. In the near future, we will concentrate on the development of obstacle-avoiding routing algorithms. To support the routing process, different data models will be considered and extended to represent the first responders, disasters and spatial information.

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