An adaptive system for movement decision support in building evacuation

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Abstract. In this paper we propose the use of a system that provides movement decision support to evacuees. We first present a fully distributed system, which takes into account the spatial characteristics of hazard propagation. We also design and evaluate a system that is based on a decentralised architecture. We use a multi-agent simulation platform for building evacuation that we developed, in order to evaluate our proposed systems.

1 Introduction

There are various approaches regarding the problem of movement decision support during emergency situations. In [1] the authors propose a distributed algorithm for robot navigation using a sensor network and evaluate their approach using a robot and a sensor network composed of nine nodes. The authors in [2] propose an algorithm inspired by sensor network routing, in order to guide a flying robot. The evaluation scenario included only one human and twelve sensors positioned inside a building. In [3] a system based on sensor networks is proposed, for navigating the user to a goal location by avoiding hazardous areas. The path calculation algorithm is based on artificial potential fields.

Our goal is to design a system that operates during an emergency situation inside a building. The system should adapt to the changes of the environment and provide directions to the evacuees regarding the best available exit, in real time. We present a fully distributed system and a decentralised system that we have designed and compare their performance in various evacuation scenarios and different buildings architectures.

2 The Decision Support System

Our system is composed of a number of Decision Nodes(DNs) positioned in specific locations inside the building, whose role is to compute the best direction

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towards an exit. This is communicated to the evacuees via a dynamic panel or via a wireless device, such as a PDA, which is carried by the evacuees and receives the direction information from the DNs. We also assume that there is a network of sensor nodes installed in the building. Their role is to provide real-time information to the DNs regarding the conditions inside the building, such as the presence of fire or smoke. The known building layout is used to create a graph G. Each vertex of G represents a location where people can congregate, while a link between two vertices corresponds to a physical path that can be followed by the evacuees. The length $l(i, j)$ of a link (i, j) is the actual distance of the path between two neighbouring DNs. Each of the wireless sensors is associated to a link (i, j) and measures the intensity of the hazard $H(i, j)$ along the link. When there is not a hazard present, $H(i, j) = 1$ and its value increases along with the value of the observed hazard. We define the *effective length* of a link as: $L(i, j) = l(i, j) \cdot H(i, j)$. This metric expresses how hazardous a link is for a civilian that will traverse it. A DN is positioned at each of the vertices of the graph G, while a sensor node monitors the hazard intensity along a link between two DNs.

This paper extends the work that was presented in [4]. We let each sensor communicate with its neighbours and incorporate their readings into the "spatial" hazard value H_{sp} it reports. The number of neighbours with which a sensor can communicate is defined by a radius R. Let m be a sensor measuring the hazard level H_m on link (i, j). A sensor n measuring the hazard level H_n on a link (i', j'), belongs to the neighbours set $N(m)$ of m, if: $d(m, n) \leq R$, where $d(m, n)$ is the Euclidean distance of the sensors locations and R defines the radius of the neighbourhood area. The effective length $L_{sp}(i, j)$ that includes the spatial hazard information is given by $Lsp(i, j) = l(i, j) \cdot H_{sp}(i, j)$, where $H_{sp}(i, j) = H(i, j) + \frac{1}{|N(m)|} \sum_{k \in N(m)} H_k$.

The distributed decision support algorithm that our system uses, is inspired by adaptive routing techniques such as the Cognitive Packet Network [5]. When the decision support system is in operation, each DN at u periodically executes Algorithm 1 and provides a suggestion to the evacuees that are in its vicinity. The suggestion is of the form **"go to v"**, where v is a neighbour of u.

Let us now present an algorithm that is based on a decentralised architecture. It uses a replicated data structure (i.e. the area graph), initially distributed to all the DNs. When a change in the environment occurs, due to the spreading of the fire, the DN that is close to the respective location detects this event. In order to inform the rest of the DNs regarding this change, the system must propagate this information to all the DNs. This process of updating the DNs can be achieved via flooding. Each DN compares the current value of the effective length $L(u, n)$, for each of its incident links, with the previous value $L_{old}(u, n)$. If a change is detected, it initiates the process of flooding so that the rest of the DNs can be informed. A message containing updated information information regarding the effective lengths is created and propagated inside the network. Such a message does not depend on the size of the area. Moreover, when a DN receives a metric

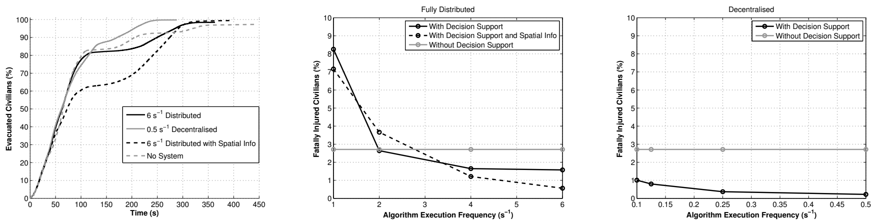
Algorithm 1 Distributed calculation for the effective length $L_{sp}(u, e)$

Send to every neighbour n of u, the effective length of the path from u to the exit $e : L_{sp}(u, e)$
for each sensor node monitoring a link incident to u **do**
  Request hazard intensity H_{sp} from sensor node
  Calculate the effective length $L_{sp}(u, n)$,where n is a neighbour of u
end for
Update the effective length $L_{sp}(u, e)$ of the shortest path to the exit:
$L_{sp}(u, e) = \min \{L_{sp}(u, n)+L_{sp}(n, e)$: $\forall$ neighbours n of $u\}$
Set the next suggested Decision Node v:
$v = \operatorname{argmin} \{L_{sp}(u, n) + L_{sp}(n, e)$: $\forall$ neighbours n of $u\}$

update message, it only needs to update its local copy of the graph and forward the message to its neighbours (except the one from which it received it).No further processing of the message is necessary. Thus, in the implementation of the decentralised system we have made the assumption that the update in the graph of each DN, as a result of flooding, is performed rapidly. This way, each DN is able to have an up to date representation of the conditions inside the building when it locally executes the algorithm that calculates the safest path towards an exit. Each DN has locally available a global graph $G(V, E)$ of the area, where V is the set of DNs deployed in the building and E is the set of links between the DNs. Using the graph of the building, each DN executes a centralised version of the previous algorithm in order to provide a suggestion regarding the best direction towards an exit.

3 Simulation Results

We have implemented the proposed decision support system inside the Distributed Building Evacuation Simulator (DBES) [6]. When we use the decision support system during the evacuation procedure, the civilians move according to the directions of the DNs. When the evacuation procedure takes place without the use of the decision support system, each evacuee has full knowledge of the building's graph and decides his next destination by the use of Dijkstra's algorithm. When an evacuee reaches a hazardous area, he updates his representation of the building's graph and recalculates the shortest path. Between successive simulation runs, the civilians' initial locations and the spreading rate of the hazard are randomly chosen. The evacuation scenario takes place in a three storey building with three stair cases which provide access to the different floors and four exits located on the ground floor. A fire starts spreading on the ground floor of the building. The occupancy of the building is 60 civilians. The value of the radius of the sensor neighbourhood area is set to $R = 2m$. For each of these cases, we executed one hundred simulation runs. Figure 1 shows that when the system is in use, the civilians evacuate the building faster, avoiding exposure to the hazard. The decentralised system in some cases outperforms the fully distributed one, at the cost of limited scalability and increased memory requirements. Moreover, the use of spatial hazard information further improves the performance of the distributed algorithm.



(a) (b) (c)

Fig. 1. Simulation results comparing the performance of the different algorithms

4 Conclusions

We designed and evaluated two algorithms used by a movement decision support system during an evacuation. The first is based on a fully distributed architecture while the second relies on a decentralised approach. We also compared our results against the case where a decision support system is not used. The overall evacuation outcome is improved by the use of the decision support system, since the civilians are able to reach an exit faster, by avoiding exposure to the hazard.

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