Incorporating a Model of Human Panic Behvior for Robotic-Based Emergency Evacuation

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Abstract— **Evacuating a building in an emergency situation can be very confusing and dangerous. Exit signs are static and thus have no ability to convey information about congestion or danger between the sign and the actual exit door. Emergency personnel may arrive too late to assist in an evacuation. Robots, however, can be stored inside of buildings and can be used to guide evacuees to the best available exit. To enable this process, evacuation robots must have an understanding of how people react in emergency situations. By incorporating a model of human panic behavior, these robots can effectively guide crowds of people to zones of safety. In this paper, we discuss an initial design of these robots and their behaviors. Preliminary simulation results show that a significantly larger proportion of people are evacuated with robot assistance than without.**

I. Introduction

Shouting "FIRE" in a crowded movie theater can cause many injuries and even deaths in the subsequent panic and rush to the exits. In a real fire, with smoke and alarms, the panic is even worse. Previous emergency situations have shown fatality rates from 50 out of 3000 [10] to 55 out of 119 [7]. Even simulated emergencies can cause injuries in volunteers [7], [11]. On the other hand, a swarm of autonomous robots can be used to help guide people towards exits at a reasonable pace. These robots would be stored in strategic places inside of large buildings, such as malls and convention centers. They would be activated along with fire alarms when the building needed to be evacuated.

Emergency evacuation robots offer many advantages over traditional methods of notification and guidance. Typically, the only notification that people receive about an emergency is a buzzing alarm. The only guidance they receive comes from stationary signs and their own recollection. Emergency personnel can assist, but they need time to arrive at the site and they take a great risk by entering a building during an emergency. Robots can be stored inside the buildings and become active as soon as an evacuation is called. They can approach people and guide them out of the building with no danger to emergency personnel.

To enable this process, this work has simulated how humans evacuate buildings during an emergency. Simulated robots were created to help guide the humans to exits. In its final form, the robot swarm as a whole will take input from a human operator so that each group of people is guided to the best exit. Individual robots will use simple rules inspired by swarm intelligence to determine to what extent they follow the operator's commands and to what extent they exhibit other behavior. Other behaviors include searching for injured people and circling around to catch stragglers.

II. Related Work

A. Panic Models

Several studies have been performed on how people react in emergency situations. One of the most interesting studies interviewed 128 survivors from a fire in the Solarium of the Summerland Leisure Complex in 1973 [10]. Sime found that individuals with strong ties to a group were less likely to panic and try to escape in a selfish way than previously thought. He found that families and groups of friends were more likely to make escape choices that were better for the group as a whole. Sometimes, particularly tight groups would exhibit this behavior at great personal risk. One example of this would be a parent refusing to leave a burning building without his/her child. This study showed that some families that were not together at the onset of the emergency still found each other and were grouped at their exit. The affiliate behavior was greatly dependent on the closeness of the group. Families were much more likely to stay together, close friends somewhat less and casual acquaintances (such as those who met at the resort) were unlikely to stay together at all.

Another study analyzed video of crowds panicking during the 2006 Hajj in Mecca, Saudi Arabia [6]. The researchers plotted the position and velocity of each person in the area immediately in front of a bridge entrance. From this, they determined when the crowd transitioned from laminar to stop-and-go or turbulent flows. Using this data, they made several recommendations to the Saudi Arabian government to improve the flow of pedestrians and reduce the number of casualties. These recommendations included making certain pathways one-way, discouraging stops on walkways, and tracking the number of people in each area.

A final study experimented with what exit individuals chose in a simulated emergency [2]. Benthorn recruited volunteers and had them test an emergency situation at an IKEA store. Each volunteer was given a headset which played an alarm and gave instructions to evacuate as quickly as possible. The study found that when volunteers could see closed exit doors nearby they still preferred to go out through the front of the store, but when they could see an open exit door (such that they could see outdoors) then they were more likely to take it regardless of distance.

B. Aircraft Evacuation

Several experiments have been run to determine how people evacuate airplanes during emergencies. Muir has performed many tests with over one thousand paid volunteers to discover how people behave during an evacuation. During one test, the researchers tried several different aisle widths in front of the wing exits [7]. They determined that wider aisles (up to approximately 20 inches) allowed more people to evacuate. Greater than 20 inches of width and the aisle became wider than the exit itself, so evacuees assumed that more than one person could leave at a time. This was not possible due to the width of the exit itself, so this caused a bottleneck in the exit row. Muir also examined what happened when volunteers were given extra incentive to evacuate quickly. This incentive was an additional $7.75 over their pay as volunteers if they could be among the first 50% to evacuate. For over the wing exits, this actually increased the mean time for evacuation. Some volunteers would push through bottlenecks to get out faster, which only delayed the group as a whole. Volunteers would also climb over seats (the authors note that not all seats were empty) to jump ahead in the line. This selfish and somewhat irrational behavior complements Sime's work in determining when groups work together to evacuate.

C. Search and Rescue Robots

Considerable research has been done on using robots for search and rescue applications. Bethel and Murphy studied how volunteers reacted to rescue robots in a simulated urban disaster [3], [8]. They created several recommendations for how robots should approach, contact and interact with the victims. For the approach and other motions, the researchers suggest using smooth acceleration and deceleration. In contrast, typical robots are usually jerky when moving in an unknown environment. The researchers also suggested using blue lighting around the robot to convey a sense of calm. For interaction, they note that there are several different "zones" where the robot can be: the intimate zone (0 to 0.46 meters), the personal zone (0.46 to 1.22 meters), the social zone (1.22 to 3.66 meters) and the public zone (further than 3.66 meters). Robots are assumed to stay in the social zone or closer. To communicate, the researchers assumed that the robots would have to be in the intimate or personal zones. They suggested using voice communication to reassure the victim and music when there is no information to communicate.

III. Methodology

Several studies of emergencies were combined to create a rule-based model of human panic behavior. This model was then used to create rules for robots to follow during an evacuation.

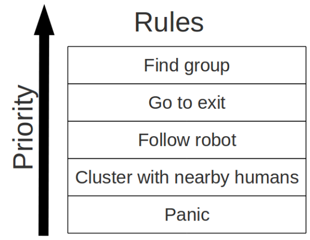

Fig. 1. High Affinity Rule Priorities

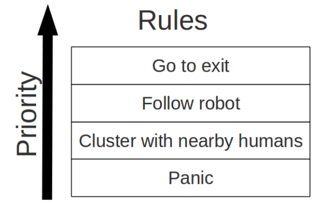

Fig. 2. Low Affinity Rule Priorities

A. Model of Human Panic Behavior

Rules for the human panic model were defined such that humans would find other humans, move towards exits or exit signs and follow evacuation robots. These rules were given priorities (see Figures 1 and 2) to model which rule humans are likely to follow in each situation. The highest priority rule that could be executed was followed in each situation.

Using Sime's research [10] the model accounts for group affiliation. High affinity groups first search for other members of their own group before attempting to exit. This is similar to behavior seen by family members who search for their entire family before exiting. This rule superseded all other rules, including those that would allow the individual to exit sooner.

The next rule defined how humans assembled as a group, regardless of affinity. Lower affinity groups used this as a first rule, while higher affinity groups would follow this rule only after their group was assembled. This rule is similar to actual behaviors during emergencies where people tend to crowd together in hopes of finding an exit. This behavior also means that as humans tend to move towards a robot or exit, other humans who cannot see the exit or robot but who can see the humans will tend to move towards safety.

The model dictates that humans will follow the evacuation robots as soon as the robots are seen. This assumes that humans will treat the robot as an exit sign and head directly towards it while trying to maintain some group cohesion with nearby humans and family groups. Similarly, the model has a rule that humans will proceed directly to an exit as soon as it is seen. High affinity groups will make sure that others in their group are likely to see (and thus exit) before they exit themselves. This assumes that the humans know that the exit leads directly outside, similar to [2].

Information on how people recognized exit signs was taken from [4] where disabled people in assisted living rated the visibility of various exit signs. A sizable minority of these people had vision problems. This paper had some surprising results as it shows that there is a small difference between the distance at which the people with seeing disabilities can recognize an exit sign (mean of 13.9-14.6 meters depending on the sign) versus those without seeing disabilities (14.5-14.7 meters). The study found that people can recognize an exit sign at a point several meters past where they can read the word. This and other work confirms the idea that the robots should use a familiar sign to guide people [1], [5], [9]. A familiar exit sign mounted on a robot should be just as visible as an exit

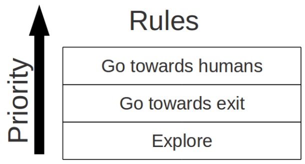

Fig. 3. Evacuation Robot Rule Priorities

sign mounted on a wall, so the model uses the same distance for recognition of each.

The lowest priority rule for the model is that a human would panic. This rule would only be executed when no humans, exits or robots are near enough to be seen. This rule models how people move randomly (if at all) in a panic. Placing it at the lowest priority is justified by Sime's assertion that humans do not actually panic often in an emergency [10].

B. Evacuation Robot Behavior

A rule-based behavior was created for the evacuation robots with priorities applicable in each situation. To best accommodate the human's rule to follow robots, the robot starts by attempting to approach as many humans as possible. Once it has attracted as much attention as possible, the robot starts to head towards the nearest exit. As the robot approaches the exit it starts to oscillate between these two rules. This produces a behavior where the robot goes back for humans that are slower. Once the humans start to exit, the robot starts to head towards the back of the group of humans so that it can guide those who may not be able to see the exit yet. Once all humans within sensor range have been evacuated, the robot explores to find more evacuees. The priorities for these rules can be seen in Figure 3.

IV. Simulation and Results

A simulation of humans and evacuation robots was created to determine what affect the robots had on evacuation rates. Humans and robots were each simulated with a rule-based planner and simple trajectory planning. Each entity was allowed to move one unit of distance each iteration. For the purposes of this experiment, units of distance and time are fairly meaningless. Four exits were placed in the 500 by 500 unit environment, one at each corner. The simulation was run for 1000 iterations (enough time for an entity to cross the width of the environment twice). Two versions of the simulation were run: one with robots and one without. The percentage of humans evacuated in this time was used as a metric. Time to evacuate all humans could not be used as the metric because when no robots are present to help evacuation there is no guarantee that all humans will evacuate.

A. Human Simulations

Humans were given full 360 degree awareness of objects near them. This was preferably to simulating every sensory organ as well as head movement. They were given a sight range of 100 units to see lighted objects, such as robots and exit signs, but only 50 units for other humans. According to

Algorithm 1 High Affinity Group Guidance

```
groupCentroid = average(all members of group)
humanCentroid =
  average(all humans within 50 units)
if dist(groupCentroid, myPosition) > 50:
  goal = groupCentroid
else if dist(nearestExit, myPosition) < 100:
  goal = nearestExit
else if dist(nearestRobot, myPosition) < 100:

  goal = average(nearestRobot, humanCentroid,
     groupCentroid)
else if dist(nearestHuman, myPosition) < 50:

  goal = average(groupCentroid, humanCentroid)
else:
  goal = randomPoint
```

(Boyce, 1999), exit signs should be recognizable at approximately 15 meters, but there has not been a similar study to determine how far away a human can see another human in this situation.

Humans were split into 20 groups with random sizes in a Gaussian distribution with mean of five and standard deviation of two distance units. Each group was given a random affinity value between zero and one. The groups were placed in the environment on a Gaussian distribution centered at a random point with a 50 unit standard deviation in each dimension. Each human's behavior depended on their group affinity, the proximity of humans around them, visible exit signs and nearby robots.

1) High Affinity Groups: Groups with affinity over 0.5 were classified as close-knit groups, such as families. These humans' highest priority was to find the other members of their group. As a first choice, group members would proceed to the average position of the other members of their group, regardless of their distance. They would ignore all other humans, robots and even exits to do this. It was assumed that the family was able to communicate over larger distances than they could see. Once the group was together, they would look for an exit. If an exit was within 100 units then they would proceed to that. If not, they would look for a robot within 100 units. If they could find a robot, they would proceed towards that robot as a group. Each human averaged the centroid of all humans within 50 units, their family's centroid, and the robot's position to determine their new goal position. If no robot was found, human would simply average their family's centroid with the centroid of visible humans and head to that spot. If no humans or robots were in range, the human would panic and move randomly. The method to determine a high affinity group member's goal can be seen in Algorithm 1.

2) Low Affinity Groups: Groups with affinity less than or equal to 0.5 ignored their group. If an exit was available, they would proceed directly towards it. If a robot was visible (100 units), they would proceed towards the average of the centroid of any visible humans (50 units) and the position of the robot. This produced a line of humans following the robot. If no robots were nearby, the human would proceed

Algorithm 2 Low Affinity Group Guidance

```
humanCentroid =
  average(all humans within 50 units)
if dist(nearestExit, myPosition) < 100:
  goal = nearestExit
else if dist(nearestRobot, myPosition) < 100:

  goal = average(nearestRobot, humanCentroid)
else if dist(nearestHuman, myPosition) < 50:
  goal = humanCentroid
else:
  goal = randomPoint
```

Algorithm 3 Robot Guidance

```
goal = nearestExit
humanCentroid =
  average(all humans within 100 units)
if 50 < dist(humanCentroid, myPosition) < 100:
  goal = humanCentroid
else if dist(goal, myPosition) < 50:
  goal = randomPoint
```

to the centroid of the visible humans (50 units). Again, if no humans or robots were nearby then the human would panic and move randomly. The method to determine a low affinity group member's current goal can be seen in Algorithm 2.

B. Robot Simulations

Robot simulations were given sensors that could detect humans within 100 units in any direction. They were programmed to know the position of each exit. Four robots were used for the experiment. They were placed at positions towards the center of the environment. Robots were given an initial goal of their nearest exit. If no humans were within 100 units, the robot would proceed towards that goal. If humans were within 100 units, the robot would proceed towards the centroid of all visible humans. Once the centroid of these humans was within 50 units, the robot proceeded towards the nearest exit. If the centroid of humans drifted outside of the 50 unit range, the robot would turn back to try to gather them again. Once the robot reached the exit, it would wait for all humans to exit and then head to a random point in the environment. If it intercepted humans along the way, it would start over and guide them to the nearest exit. The function to define the robot's current goal can be seen in Algorithm 3.

C. Results

After 20 iterations, the following results were found. Figure 4 shows the mean percentage of humans evacuated in 1000 iterations. The percentage with robots is in blue, and without is in red. Figure 5 shows the standard deviation. Again, the standard deviation with robots is in blue, and without is in red. A one tailed T-Test was performed. The T-value was 24.8, which has a significance value of better than 0.01 for 18 degrees of freedom.

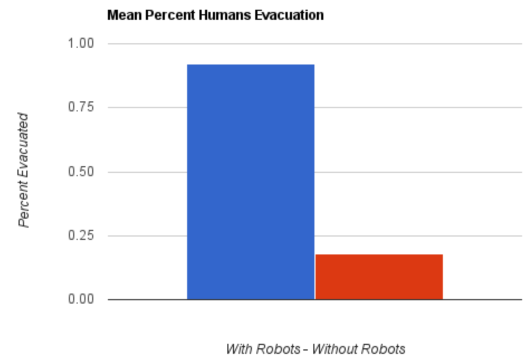

Fig. 4. Mean Percentage of Humans Evacuated

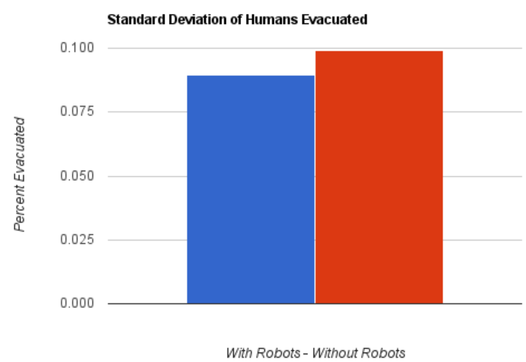

Fig. 5. Standard Deviation of Humans Evacuated

V. Discussion

It is no surprise that the results show that robots helped to evacuate many more people than trials without robots. So far, the human models do not allow for much exploration, so if they cannot see a robot or an exit sign they are doomed to wander. Some interesting behaviors emerged during the simulation. In Figure 6, the robots and humans can be seen at their starting positions. Robots are shown as red circles. Exits are shown as red squares. Humans are given a color coding for their group. Note that some colors are reused, so only those with the same color in the same proximity belong to the same group.

In Figure 7 the humans can be seen converging on the robots. The interesting point to note here is that the humans towards the end of the line cannot see the robot, they are simply following the group in front of them. This shows that, according to the current model, not every person in a group needs to be directly lead, some will follow others in the hopes that they are heading to safety.

In Figure 8, a nice, orderly line can be seen in the top right. Note that this was from a different simulation than the previous figure, but it is typical. A narrow 'V' can be seen in the lower left. The lower right is more disjoint because the group was less orderly to start with. They are in the process of exiting. Note the two groups along the left who have missed

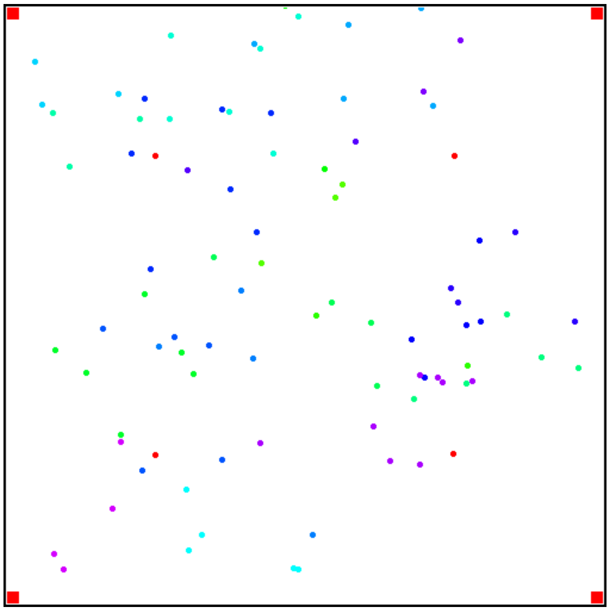

Fig. 6. Initial Setup

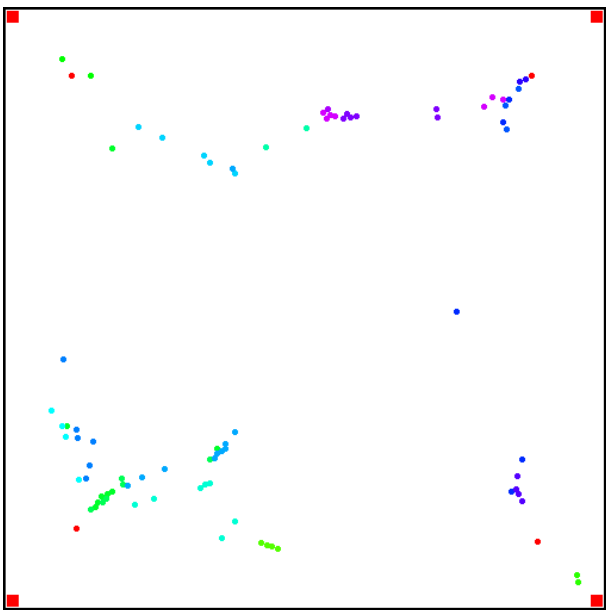

Fig. 7. Lines Forming Behind Robots

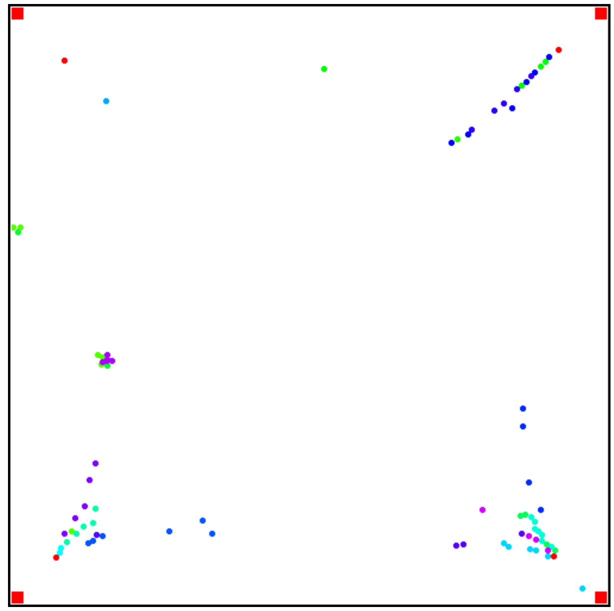

Fig. 8. More Defined Lines Behind Robots

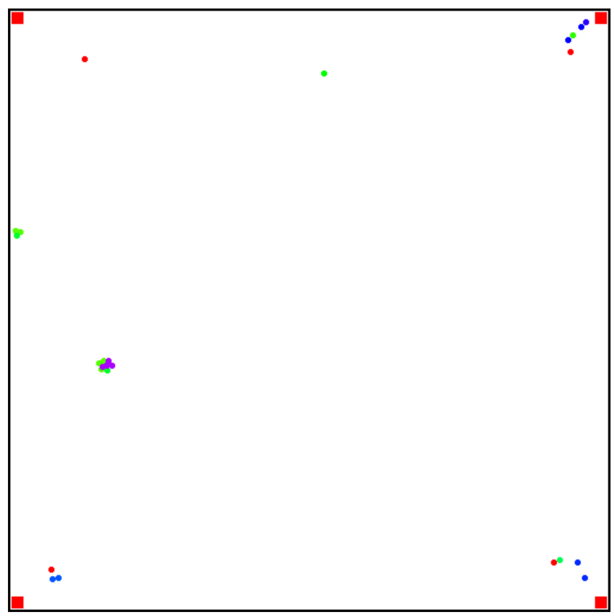

Fig. 9. Robots Waiting for Humans to Exit

the robots and the one straggler along the top.

In Figure 9, most of the humans have exited and the robots are simply waiting for the last humans in their immediate area to leave. The robots will oscillate somewhat at this step as they move toward stragglers at the end of the line and then guide them towards the exit.

Finally, in Figure 10, the robots are exploring again to look for survivors. The robot in the top left has found a straggler and is guiding him/her back to the nearest exit.

So far, the robots are not coordinating with each other to cover the available area better. Also, there is no human operator yet to guide the robots. When these steps are implemented, the survivability should go up.

VI. Conclusions

An emergency evacuation has been simulated using basic models of human panic behavior. Simulated robots were used to find and guide humans towards exits. It was shown that more humans were evacuated with than without the robots.

The next step in this work is to run this simulation in the Player/Stage simulation environment using Robot Operating System. This will make several algorithms for obstacle avoidance available and will also help to simulate the robots in a more realistic environment.

The panic models used for humans need to be refined. Statistics from Simes' work will be used to create realistic numbers of high and low affinity groups. A third level of group will be added between those to allow for loose group

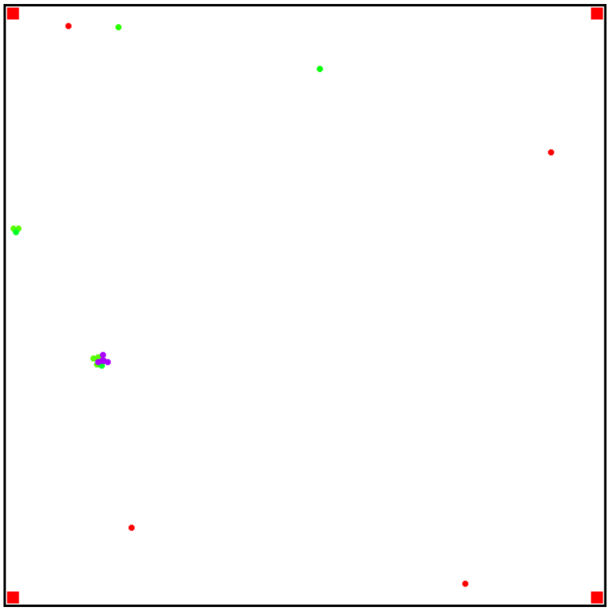

Fig. 10. Robots Looking for More Humans

affiliation. In future work, groups need to make decisions together, possibly by picking a leader and then following him/her. Group affiliation at the start of the emergency is an important factor in whether the group stays together or not, so that will have to be studied.

The robot behaviors need to be improved, as well. The robots must work together to efficiently search the area. Input from a human operator should also be considered, especially towards the end of the search. Behaviors need to be created to allow the robots to effectively interact with humans, as in Murpy's work.

REFERENCES

[1] Emergency evacuation planning guide for people with disabilities. Technical report, National Fire Protection Agency, 2007.

[2] L. Benthorn and H. Frantzich. Fire alarm in a public building: How do people evaluate information and choose an evacuation exit? *Fire and Materials*, 23(1):311–315, 1999.

[3] C. L. Bethel and R. R. Murphy. Survey of non-facial/non-verbal affective expressions for appearance-constrained robots. *IEEE Transactions on Systems, Man, And Cybernetics Part C*, 38(1):83–92, 2008.

[4] K. E. Boyce, T. J. Shields, and G. W. H. Silcock. Toward the characterization of building occupancies for fire safety engineering: Capability of people with disabilities to read and locate exit signs. *Fire Technology*, 35(1), 1999.

[5] B. Collins, M. Dahir, and D. Madrzykowski. Evaluation of exit signs in clear and smoke conditions. Technical report, National Institute of Standards and Technology, 1990.

[6] D. Helbing, A. Johansson, and H. Z. Al-Abideen. Dynamics of crowd disasters: An empirical study. *Physical Review E*, 75(4), 2007.

[7] H. Muir, D. Bottomley, and C. Marrison. Effects of motivation and cabin configuration on emergency aircraft evacuation behavior and rates of egress. *International Journal of Aviation Psychology*, 6(1):57–77, 1996.

[8] R. R. Murphy. Human-robot interaction in rescue robotics. *IEEE Transactions on Systems, Man, and Cybernetics, Part C Applications and Reviews*, 34(2):138–153, 2004.

[9] M. S. Rea, F. R. Clark, and M. J. Ouellette. Photometric and psychophysical measurements of exit signs through smoke. *NRC Publications Archive*, 1985.

[10] J. D. Sime. Affiliate behaviour during escape to building exits. *Journal of Environmental Psychology*, 3:21–41, 1983.

[11] L. J. Thomas, K. J. Robinson, A. M. Mills, and H. C. Muir. Operation of a conventional type iii exit hatch: Passenger perceptions and performance. *FAA Fire and Cabin Safety Research Conference*, 2001.